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THE INAUGURATION OF THE STATUE OF NIEPCE.

On June 21, 1885, the statue of Nicéphore Niepce, the inventor of photography, was inaugurated in the pretty town of Châlon on the Saône, whose quays with their life and bustle were formerly the admiration of travelers, but are now silent and unused, the weeds growing in the cracks of the pavement.

This recognition of the inventor's work was due to Niepce, who during his lifetime was poor and unknown, although photography is, unquestionably, one of the greatest inventions of modern times. Justice has finally been rendered him, and this bronze statue, the work of Mr. Guillaume, stands to-day on the bank of the Saône. It represents the inventor with his head raised, looking at the sun, while the movement of his right hand seems to indicate that it is by the rays of the sun which entered the camera that he obtained such great results. In his left hand, which rests on the camera, he holds the first heliographic proof made, a portrait of Cardinal d'Amboise. This plate is preserved in the museum of Châlon. The pedestal was made from the plans of Mr. Narjoux, an architect of Paris, and Mr. Poinet, an architect of Châlon.

The sun was obscured until noon, but appeared at the right moment to assist at the fête, which was partly its own. Addresses were delivered by the mayor of Châlon and others, and a poem was read by Mr. Lucien Pate.—*L'Illustration.*

A SKETCH OF ROMAN BUILDING CONSTRUCTION.*

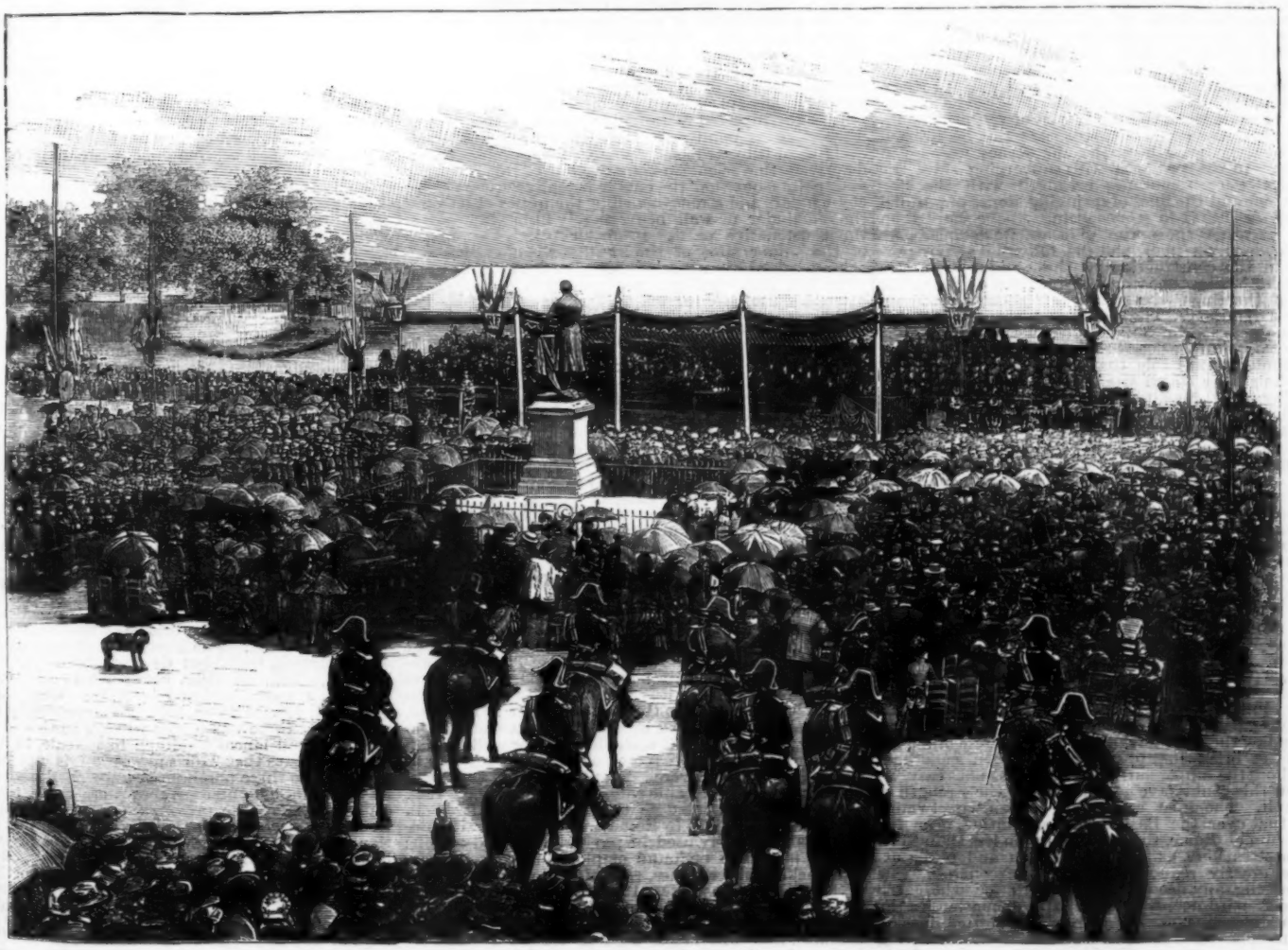
By W. T. Oldrieve.

To disentangle the architectural conceptions of a people from that which is borrowed or inherited by tradition, leaving that which can justly be called their own, is a task by no means easy. Architectural writers have, in attempting it, entered upon an arena of strife which, to the amateur and the professional student, is not a little perplexing. It is only necessary in this "sketch" to assume that we may legitimately call that Roman which the Romans first made a principle of construction or design, although the primary forms adopted may have been previously used by other nations. It is proposed to consider the subject under—I. Principles and forms of Roman construction. II. Processes and methods. III. Materials and workmanship.

* Being the Cousin Prize Essay in the Class of Fine Art, Edinburgh University, Session 1884-85.—*Building News.*

I. PRINCIPLES AND FORMS.

Although the Romans used the three "orders," it was in some important respects in a different manner to that in which the Greeks made use of them. The Romans did not rest satisfied with them, nor did they enter wholly into the spirit of an epistyle construction as the Greeks, whose purity of form and delicacy of line were never appreciated by the Roman architects. While the architecture of the Greeks is expressive of an artistic and refined simplicity, that of the Romans is expressive of vast resources, indomitable energy, and great constructive skill. The Greeks so designed their buildings that no decoration or adornment was needed as a necessity to make them artistic, for the artistic spirit is in the construction. Not so is it, as a principle, with the architecture of the Romans; the form which covers the construction is often independent of it. This may be stated as a first principle in Roman construction. Undoubtedly the most characteristic feature in the buildings of the Roman period is the arch. The Romans first used it in a true sense architecturally and consistently, although its use can be traced back, in a more or less perfect form, to almost all the ancient nations. In adopting the arch as an architectural feature, the column and the entablature were not discarded by the Romans, though they show by their great vaults and domes that they could constructively have been dispensed with. It is generally assumed that in the combination of arch and epistyle in a Roman facade, the arch and wall are Roman, and the column, etc., are borrowed from the Greeks. Semper has entered a protest against this assumption, and asks why the column should be borrowed by the Romans from the Greeks, when both nations belonged to the same family and started with the same traditions, and when the column is found as early in Italy as in Greece. It is probable that the column and entablature were used as the natural construction, and the wall and arch introduced in the buildings of several orders in height, as the Colosseum, to support the upper stories as well as to form an outer screen. A feature was thus added which gave increase of strength while preserving the columnar principle. Viewed in this way, the Roman combination of column and arch



INAUGURATION OF THE STATUE OF NICEPHORE NIEPCE, AT CHALON-SUR-SAONE.

is not an architectural scandal, though this is frequently taught. It is considered not improbable that this combination was introduced from some of the Hellenistic cities, though its introduction does not seem to have been clearly traced. The first Roman example is believed to be the Tabularium at Rome, B. C. 78. Another combination of the same nature, though less defendable, is the use of piers or mullions in an arch-headed aperture. This can only be mentioned here. The Pantheon at Rome exhibits, in its front external elevation, the curious effect produced by the pedimented portico placed in front of a domed circular structure. Fergusson and others have held that the portico is a later addition, but authorities are pretty generally agreed that this is not so. It is in the use of the arch principle as a vault that the Romans have gained pre-eminence. Vaulting was no doubt used earlier in underground tunnels, etc., and the Hellenistic city of Mitylene in Asia Minor is supposed to have furnished the model for the first Roman stone-constructed theater on flat ground, B. C. 50, where arches supported the rows of seats; while a writer of about B. C. 40, referring to the city of Alexandria, says that the buildings were without boarding or timber of any kind, so that vaulting seems to have been in common use there. In no part of the architecture of the Romans can we get a better knowledge of the principles which guided them in their treatment of the arch. Although the vast extent of their undertakings seems at first sight to indicate that they were lavish in their expenditure of labor and materials, a more careful examination shows that there was really a feeling of economy, and that there is a correspondence between the extent of the building and the means adopted. By their scientific and constructive skill in the use of the vault, the Romans produced in their structures perfect solidity and incomparable grandeur with a minimum of expenditure. In following out our next division of the subject under consideration, we shall be able to trace in detail the carefully considered economy of parts and labor which was practiced in Roman buildings, as, for instance, the brick rib and concrete filling principle of vaulting, and the hidden buttresses in the thickness of the walls of the Pantheon, whereby greater resistance to the pressure of the vaulting was obtained than if the walls, 20 ft. thick, had been solid, though only half the quantity of materials was used.

II. PROCESSES AND METHODS.

It will be necessary, in order to keep within the limit of a short class essay, to confine our inquiry to Roman building construction in its most limited sense, not giving much attention to the great engineering works of the Romans in the shape of viaducts, bridges, etc., which they have left in so many parts of the world. Again, of the processes and methods of building construction adopted by the Roman, only those which are peculiarly characteristic need be referred to. The arch and vault were constructed both of stone and of brick and concrete; the round arch, the barrel and the domed vault being almost the only forms used. When of stone work, the arch stones, or "voussoirs," were carefully hewn to the proper form and built in alternate bands, thus economizing the centering. The old Roman baths at Nimes (now called the Temple of Diana) offer a good example of this construction. Another form of stone barrel vaulting was constructed with stone ribs and slabs between, and is interesting as bearing a resemblance to what is found in some early Christian churches in Syria. It seems a little astonishing that the Romans with all their constructive skill avoided groining in their stone cross-vaults. Wherever squared stone vaulting met, the stone construction would be stopped, and the vault worked in brick and concrete. In sloping vaults, as the entrance passages to the amphitheaters, the arching was sometimes executed in stepped rings, each separate arch standing vertically and exerting no pressure upon the lower part of vault. The inside of the stones would in this construction be dressed off to the slope, probably after the stones were set in position. In the passages with converging sides the voussoirs were sometimes arranged with the line of keystone and the lines of springing stones of parallel widths, the filling-in stones being wedge-shaped on plan. At other times the side and key stones were wedge-shaped on plan, and the filling-in stones parallel. In the construction of the oblique arch, the abutments of the stone rings were at right angles to the faces of the rings, the stones being cut to the re-required obliquity. The brick and concrete vault is most characteristic of Roman construction, although it does not date further back than the time of Augustus. It is thought probable that this too came from the Hellenistic cities. Had the great Roman vaults been "cast" entirely of concrete, the timber centering would have shrunk during the execution of so extensive a work, and caused cracks in the concrete which might have lead to an entire collapse. Viollet le Duc calculated that the centering for the dome over the Pantheon would have sunk about 20 inches in from three to six months if constructed over the whole area at once like an inverted basin. To avoid this, and to give elasticity to the whole covering, the Romans constructed light ribs of brick, and filled in between them with concrete. The brick ribs, unlike those in the Gothic periods, were not intended to be decorative features, and so were not permanently exposed. The concrete filling was economical, only easy, straightforward labor being necessary. I may also mention a building on the Palatine at Rome. Here the ribs are made up of cells formed by large flat bricks, 2 ft. square, and smaller bricks, 2 ft. by 6 in., their thickness being 2 in. The cellular construction was sometimes applied to the whole vault, as at the Palatine, and as here illustrated. The cells gave support to the concrete, both by adhesion and by their wedge shape. The concrete filling between the brick ribs appears to have been sometimes arched on the upper surface, but it is not easy to see how this could have added much to the strength of the vault. The great example of Roman barrel vaulting is that over the Basilica of Constantine, near the Colosseum at Rome, the span being no less than 80 ft. The casettes here, as in the Pantheon and other examples, greatly reduced the weight of concrete while not causing any decrease of strength, for where the casette is most deeply sunk an approximation to the form of an arch is formed, as shown by dotted lines on sketch. The wood moulds fastened to the centering before the concrete was filled in would greatly assist in securing the ribs in their position laterally. Exception might perhaps be taken to the smaller sinkings in the face of the ribs, as in the Pantheon.

If the ribs were intended to be displayed, these sinkings would certainly be most objectionable, but the objection is at least answerable when we recognize that the principle of the Roman architects was not to display the parts of construction, but to construct a framework and apply a covering, thus following the principle of overlaying, which is observed to govern many styles of architecture. There is still another method of constructing the vault which was used by the Romans, namely, that by which the vault was formed by layers of tiles or flat bricks over the centering. The arching was reduced, as much as possible, by carrying up the wall considerably above the line of springing. This system has the advantage that skeleton centering would serve the purpose of supporting the tiles at their joints. This construction is still in use in Italy. In dealing with cross vaults the Romans preferred to have two barrel vaults of the same span, but they sometimes stilted one vault to have both crowns on a level. Oblong vaults were occasionally used, but the square were preferred. The groins in cross vaulting of the brick and concrete construction were formed in a similar manner to the ribs already described; the lower edges of the bricks, however, had to be either specially moulded to the proper angle before the bricks were burnt, or cut to the exact line after being set in position. Where the groin ribs meet at the crown of vault, no attempt was made to make a finished junction or miter, one rib was carried over unbroken, and the other simply butted up against it on either side. The cross vaulting over the Thermæ of Diocletian illustrates this. Domical vaulting was executed by the Romans in a very similar manner to the brick rib and concrete barrel vaulting. At the Pantheon the ribs are probably of brick, and carried up of the same width to the top, where they abut against the curb of the hypæthral opening. Viollet le Duc thus vividly describes this masterpiece of spherical vaulting: "What, in the Pantheon at Rome, is it that produces the most lively impression? It is that immense vault which derives all its decoration from its very structure; it is that single opening for light, 26 ft. in diameter, perforated in its summit, through which the zenith is seen, and which throws upon the pavement of porphyry and granite a large circle of light. It is there that the genius of the Roman appears in full strength. So great is the elevation of this orifice above the floor, that its enormous opening scarcely affects the internal temperature. The most violent storms scarcely send down a breath of air on the head of a person standing beneath its orbit; and when it rains, the drops are seen falling perpendicularly down upon the pavement of the Rotunda, on which they describe a circle of wet. The cylinder of rain drops, falling from that height through the space of the building, renders sensible the immensity of that space. It is in conceptions like this that the Roman is really grand, because they are the outcome of his own genius, and because for their execution he borrows from no one, nor asks the aid of any artist whose nature is foreign to his." The diameter of this building is 143 ft., the height from floor to top of dome is the same, and the springing of the vault is exactly half way up. The spaces between the ribs are filled in with concrete and casetted or coffered, with four sinkings so arranged that a spectator in the center of floor sees all the margins of sinkings of equal width. A rosette of gilded bronze was originally placed in the center of each coffer, and bronze ornaments decorated the borders. An old writer states that he saw the manner of the construction of the dome during some repairs, and that there are series of arches. If this is the case, this outer system of arched reticulation must be regarded as an additional means of bracing the cupola. Nothing need be said of the portico, except that its roof was originally supported by bronze girders of the section of an inverted rectangular trough, which fact is interesting as pointing to the existence of so early an exemple of tubular metal girders. Professor Adler has described the scientific construction of this building, and points out that the cupola is really supported by eight pillars and strengthened by the upper buttresses, the remainder of wall being merely filling in between the constructive parts. Professor Adler's restoration of the upper story of the Pantheon is now generally acknowledged by authorities. Roman domes and vaults were not protected by outer roofs as in more modern examples, the interior only being considered by the architects.

III. MATERIALS AND WORKMANSHIP.

The ordinary mason's work of the Romans was not executed in large blocks of stone, as the smaller were more economically worked. It is true that large blocks of stone are found of Roman work in the temple at Jerusalem ("Opus Quadratum"), but they are evidently in imitation of the older work of Solomon's temple. Foundations and first courses are often of stone when the other parts of walls are of brick strengthened by timber. Two kinds of exterior facing to stone walls are mentioned by Vitruvius as commonly used by the Romans, "Reticulatum" (net-like) and "Incertum" (irregular). Vitruvius says that the former was the method in general use in his day, and the latter the ancient method. A limestone called travertine was much used in Rome; the Colosseum and other buildings being built of it. Travertine, Saxum Tiburtinum, is calcareous deposit found along the course of the Anio and Aqua Albula, by whose waters it is deposited, but most plentifully in the neighborhood of Tivoli, the ancient Tibur, whence its name is derived. When first taken from the rock it is soft and easily cut, but the longer it is exposed to the air the harder it becomes. This may be ascertained by comparing its state in the native rocks near Tivoli with the exterior walls of the Colosseum. For less exposed work, as the interior of walls, and where covered by plaster, soft tufa was used, and a hard volcanic substance called pepperine, which could be exposed to the air with more freedom. Very many buildings in Rome are composed of it. Basalt was principally used in paving roads and streets; but it is also to be found employed in consolidating and packing other stones, as in the interior of the wall of Servius Tullius, etc. Pumice was only used to lighten a building, as in the vault of the Pantheon and in the Colosseum. Marble was imported for monolithic columns, and was much used in slabs for lining interiors of walls, etc. It was the boast of Augustus that he had found Rome brick and left it marble. The chief supply of white marble was derived from Luna, called Marmor Lunense, and the same quarries are still worked, the marble being well known by its modern name of Carrara. The white marbles of Greece were also occasionally employed. Of colored marbles the most esteemed are the Rosso, Verde, and Giallo Antico, and Cipollino, Africano, and Pavonazetto. Roman bricks were of different forms and sizes; flat tile-like bricks were generally used, some found 2 ft. square and 2 in. thick, others 1½ ft. by 1 ft. and 1½ in. thick. A triangular form, for Opus latinitium, was also used in facing. Vitruvius devotes a chapter to a description of bricks. About the time of Constantine a practice was introduced of using large jars of baked clay (testæ) to diminish the weight of a dome or the upper part of a wall. The Romans are famous for their mortar and cement, the excellence being due to the use of puzzolana earth, which was used along with the lime. The puzzolana is a volcanic substance, and very abundant in every part of the Campagna di Roma, and the extent to which it was used is shown by the vast caverns which form the Catacombs. The name puzzolana is said to be derived from the Pulvis Puteolana, which was a similar substance found near Puteoli, now Puzzuoli. Concrete was much used, as we have already seen in considering the processes and methods of construction. It was always covered with a facing of finer material. The method of laying concrete was by an even bed of mortar 6 in. to 8 in. thick first put down, and then the stones pressed into it while soft, until the desired solidity was attained. This process was, of course, only applicable where there was resistance to lateral pressure. Plaster work (intonacum) was brought to great perfection, particularly for coating the specus of aqueducts, the interior of piscinæ, and those walls of houses which were adorned by fresco painting. Metals were not much used. The bronze beams of the portico of the Pantheon have already been alluded to. The doors of this building were of the same material. Iron was used for clamps in stonework. Lead pipes for water service are supposed to have been used. Glass was sparingly used for lighting, and as early as the time of Agrippa was employed in mosaic work. Mosaic pavement was introduced into Rome in the time of Sylla, and was largely used. Tiles appear to have been the only covering made and used for roofs. Roman works were carried out by either, 1, paid labor; 2, forced labor; or, 3, soldier labor. The materials were obtained either, 1, bought; 2, taxed; or, 3, procured from the quarries, etc., by forced labor. The regular workman had considerable political power. Trade guilds were formed and recognized by most emperors, after it was found impossible to put them down. Immunities and privileges were granted on certain conditions, as that government works should be carried out at fixed rates, etc. Time will not now permit of further notice of workmanship, and so this paper must close with a word of admiration for the constructive and organizing genius of Roman architects.

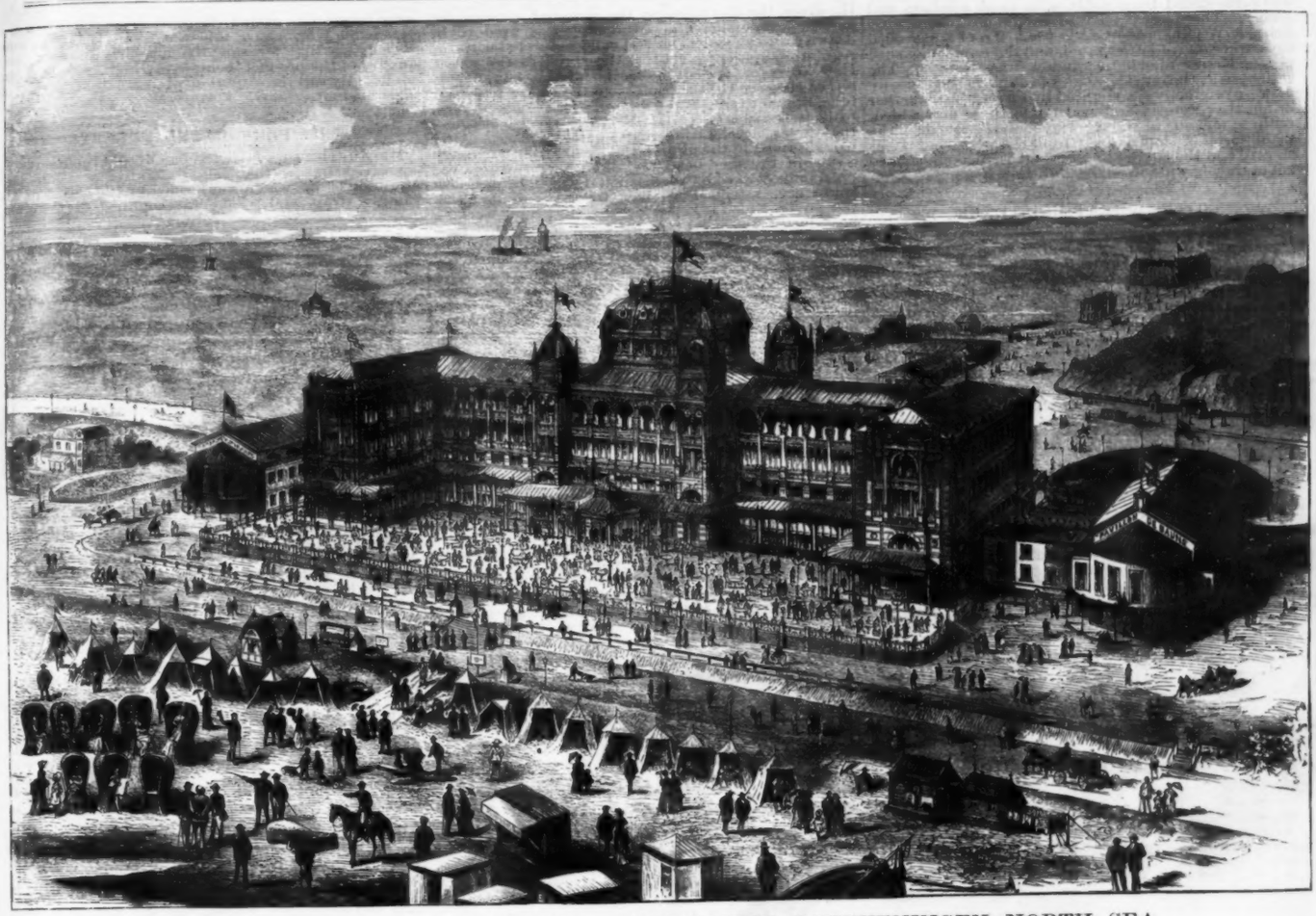
THE CASINO AT SCHEVENINGEN, HOLLAND.

IN the cut opposite, taken from the *Illustrirte Zeitung*, the new "Curhaus" or Casino at Scheveningen, on the North Sea, is shown. It was designed by Messrs. Hinkenhoff, Ebert, and M. A. Reis, the latter being the director and superintendent of the watering place at Scheveningen.

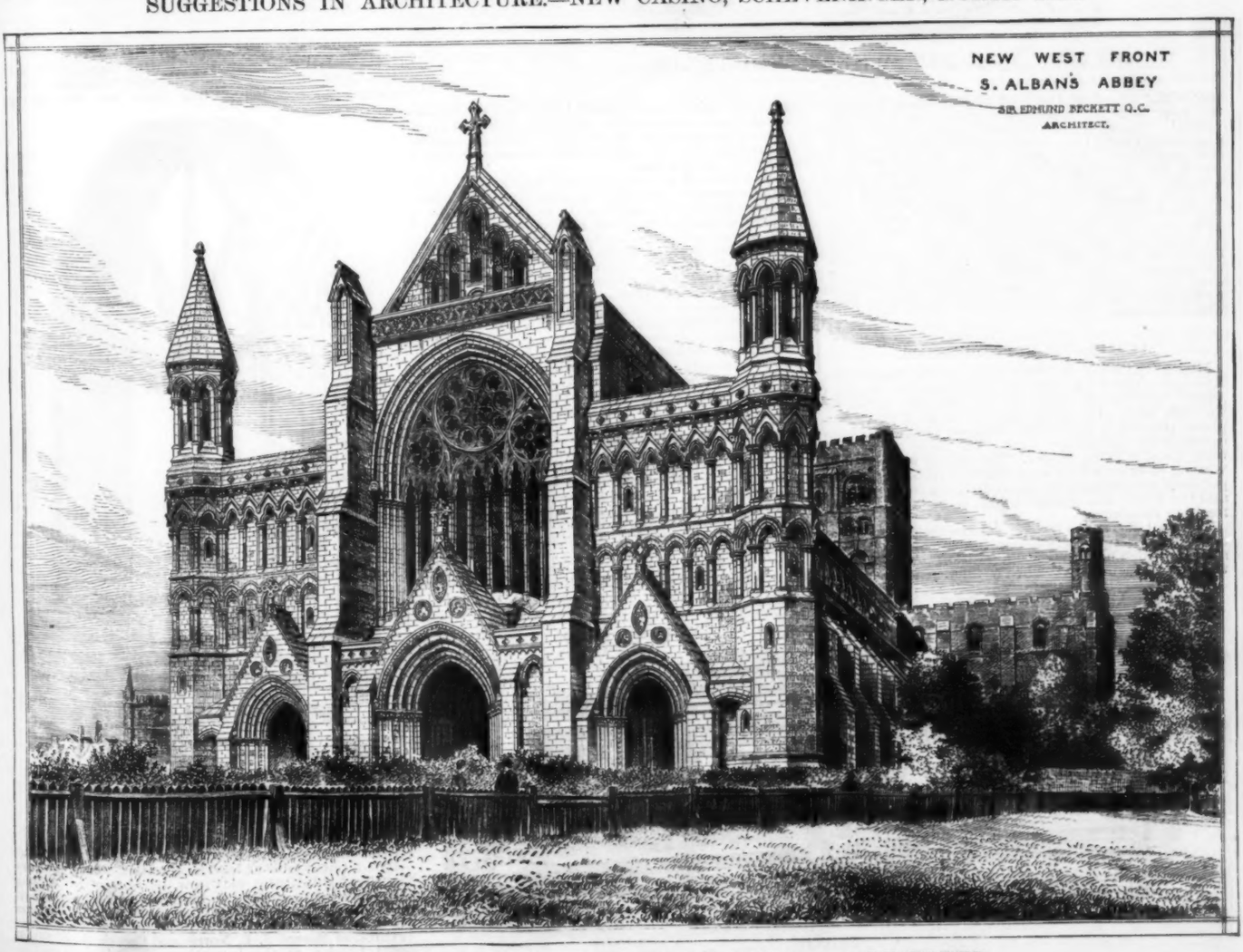
The building is constructed in the shape of an extended U, between the wings of which a platform about six feet above the dike and 426 feet wide is formed. The higher central part of the building is surmounted by a large dome, flanked at the corners by towers. On the land side a covered veranda is erected, which leads to the adjacent galleries containing the shops, etc. The facade facing the sea is also provided with verandas in which panes of glass are held movably, so that the openings in the veranda can be closed in stormy, rainy weather. The style of the building is Italian Renaissance combined with some of the elements of the Dutch Renaissance. The facades are erected in tufaceous limestone, and for the remaining parts yellowish-red bricks are used. A rich frieze of sgraffitto is arranged under the cornice, and gives an elegant finish to the upper part of the building. The center and side wings are connected by a two story loggia, as is shown in the cut. The main hall, which is in the center of the building, is of sufficient size to hold 3,000 people. It has a rich ceiling of cathedral glass, and a mosaic floor. The dining room, reading rooms, card rooms, etc., are all richly decorated. The theater is in that part of the building facing inland. The building is also to be used as a hotel.

NEW WEST FRONT, ST. ALBAN'S ABBEY.

OUR sketch, taken on the spot, shows the design, line for line, as it has been executed. Sir Edmund Beckett has paid the cost, and he has been his own architect. Messrs. Longmire and Burge are the builders, and Mr. John Chapple is the clerk of the works. We give the drawing without comment, and each reader will judge for himself as to whether the design merits the confidence with which its author seems to view it, or deserves the sweeping strictures passed upon the composition by certain professional critics and some leading architects. The work, anyway, has been very well done, and the carving throughout is excellent. The following may be taken briefly as the concise history of this west front. The Norman buildings at this end of the church, by Abbot de Paul, were pulled down by Abbot John de Cella between 1195 and 1214. The rebuilding was completed by Abbot Wm. de Trumpyngtone, from 1214 to 1235. The generally received idea is that there was a rose window in this west front then with tall lancet windows; but Neale, in his "Monograph," says that this supposition is not well supported. The three porches, we know, had high-pitched roofs, and above these porches were three tiers of arcading. Before the present works were commenced, the lowest sill of these arcadings remained in confirmation of this statement. Above the arcades were six lancet windows arranged in pairs, and inclosed by outer moulded arches, with shafts as on the north side of the nave arcade. The arcade, level with the clerestory, had windows alternating with these recessed arches corresponding with those on the exterior of the western bays of the north and south aisles of nave. Passages were continued around the west end of the nave, both at the triforia and clerestory levels. The west front



SUGGESTIONS IN ARCHITECTURE.—NEW CASINO, SCHEVENINGEN, NORTH SEA.



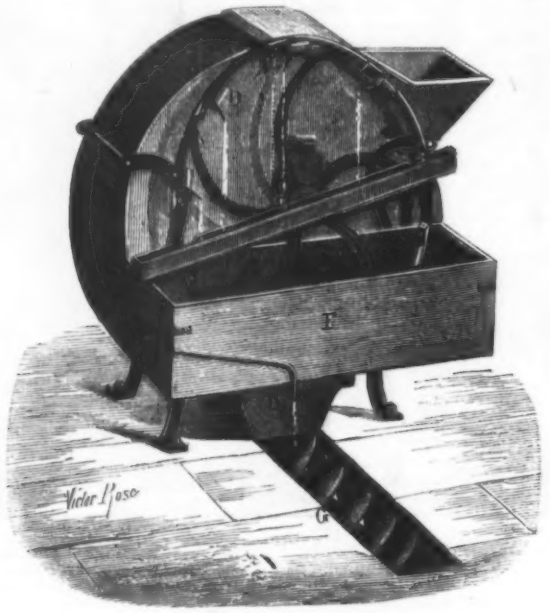
ST. ALBAN'S ABBEY.—THE NEW WEST FRONT AS RESTORED.

was surmounted by a gable, with small windows and arches. These were removed in the 15th century by John de Whethamstede, when the low roof superseded the earlier one of loftier pitch, and the now demolished perpendicular nine-light window was inserted. The staircases at the outside angles leading to the clerestory were originally surmounted by turrets, but whether or not they were as large and tall as those now added, nothing remains to show. The central gable over the main portal is sloped away from the west window, as shown, and the curved line beyond is the arch-shaped sill of the big window.—*The Building News.*

ROSE'S WHEAT MOISTENER.

As the external pellicle or pericarp of wheat is very friable, and becomes easily reduced to powder on the passage of the grain through the mill, some have conceived the idea of removing it by a sort of decortication of the grain preceding grinding. At the recent International Milling Exhibition at Paris there was shown the Dore apparatus, which performs this operation very well. The grain is submitted to a moistening, and then to energetic friction, which detaches the pellicle. The latter is then removed by a current of air.

Others again content themselves with a slight moistening, which is regulated at will according to the nature of the wheat, and succeed by this means in giving the coat sufficient elasticity to prevent its being pulverized. The exhibition showed us two types of such apparatus. One of these, constructed by Rose Bros., consists (see figure) of a wheel, to the circumference of which are affixed small buckets which dip into water beneath, and which, upon rising, pour the liquid into the chute through which the grain passes. The buckets may be fixed upon the wheel in different positions, in such a way that they shall fill more or less with water. By regulating their position, the number of revolutions of the wheel, and the velocity of the wheat's flow, the moistening may be effected in any desired proportion. The motion of the bucket wheel is determined by the fall of the wheat into the channels of the driving wheel.—*Le Genie Civil.*



ROSE'S WHEAT MOISTENER

AUTOMATIC YARN SPINNER.

MESSRS. LAWSON & SONS show at the Inventions Exhibition Good's patent automatic spinner for rope yarns. The feed-motion consists of two pairs of rollers, through which the hemp passes on to link chains placed parallel to each other, between which cross bars carrying the hackles are fixed. The hemp is fed off these hackles to the nipper. The nipper is fixed on a vertical lever swiveling on a shaft at its foot, the nipper itself consisting of two steel dies, the top one fixed, and the lower one mounted in a boss, which works freely in the nipper.

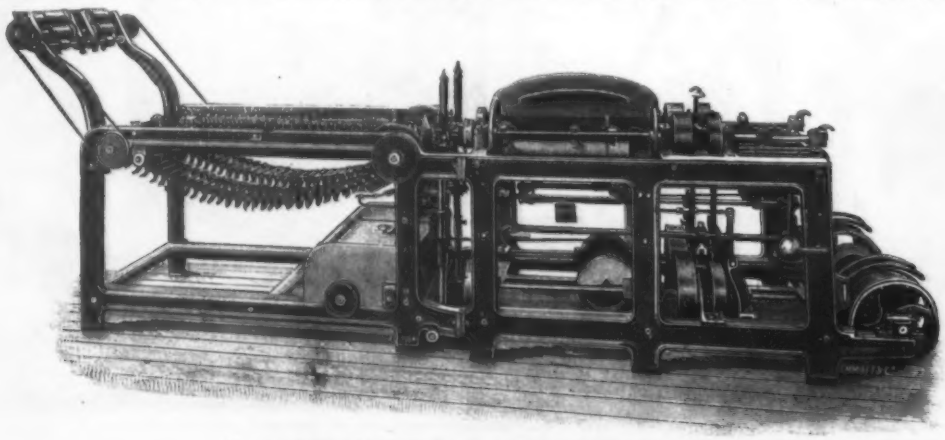
The steel dies are so formed as to be set for any size of yarn by simply tensioning the upper and lower springs, which hold the dies in position. The effect of this arrangement is that when a thick place occurs in the sliver, the dies press on the material, causing the vertical lever upon which the nipper is fixed to be drawn forward, and so move a band connected with the regulating motion to control the speed of the chain. In the case just stated the action of this motion is to retard the speed of the chain, and thus allow the sliver to be drawn to the proper quantity for the size of yarn, while in the case of a thin sliver the reverse action—that is, an accelerating motion—takes place. After being formed in the nipper, the yarn is passed through a tube in the flier head, and then over two grooved pawl pulleys fixed on the head and driven by means of spur wheels attached to them, revolving round a central pinion which is keyed on the steel tube, working loose in the flier head. At the outer end of this tube is a pulley driven by changeable pulleys to give the amount of twist required in the yarn, after which the yarn is passed over the flier on to the bobbin.

One of the chief features of the machine is a self-acting rotary drag, by means of which, as the bobbin fills, the weight applied is increased so as to make a perfect wound bobbin. On the shaft carrying the driving pulley is a clutch rubbing into another one attached to a friction disk fitting against the diaphragm of a pulley running loosely on the shaft. Between the pulley and the disk a pad of leather is placed. The loose pulley is connected by means of a strap with another pulley fixed on the bobbin spindle, this spindle being carried round by the bobbin, motion being thus communicated to the loose pulley referred to. It will be seen that the amount of pressure applied to the friction plate referred to will increase or diminish the drag of the bobbin.

A lever pivoted on a center, and constructed in an ingenious manner, regulates the pressure on the plate. This lever has for its full length, at its under side, a screwed rod which is revolved by means of a worm and wheel, and on this rod is suspended a weight, the interior of the hook of which is screwed to correspond with the rod. It will be seen that as the rod revolves it will carry the weight along with it, and as the lever is connected with the clutch, gearing with the friction plate, the pressure on the plate is increased as the weight gets nearer the end of the lever. As this operation coincides with the filling of the bobbin, the drag is thus automatically increased so as to overcome the increased velocity of the band pulley; owing to the increased size of the bobbin, a steady drag is maintained, and a well wound bobbin is the result. A stop motion is also provided so as to stop the machine on the breaking of the yarn.

The points of importance in the machine are the regular manner in which the sliver is fed, delivered, and wound, and owing to the perfect and automatic manner in which this is effected a very even and good yarn is produced. We are informed that this machine is in extensive use all over the world. It is well and strongly constructed, and is calculated to work efficiently when subjected to a considerable amount of wear and tear.

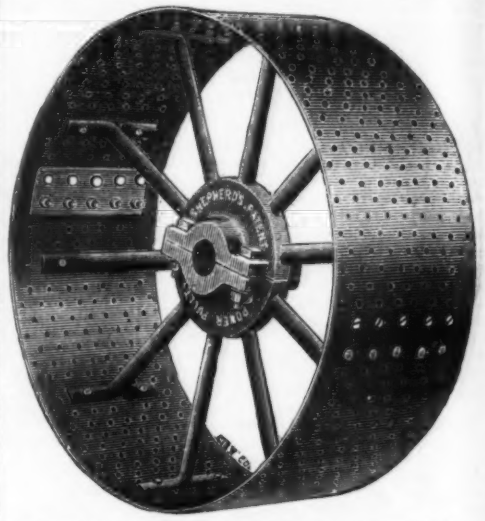
Our illustration gives a good idea of the machine, which is both novel and ingenious, and we purpose at some future date giving descriptions of the full series of machines of which this is one. In the mean time we may say that we saw the machine at work, the quality of the product being very high, and we can confidently call the attention of users of this class of machine to it.—*Textile Manufacturer.*



AUTOMATIC YARN SPINNER.

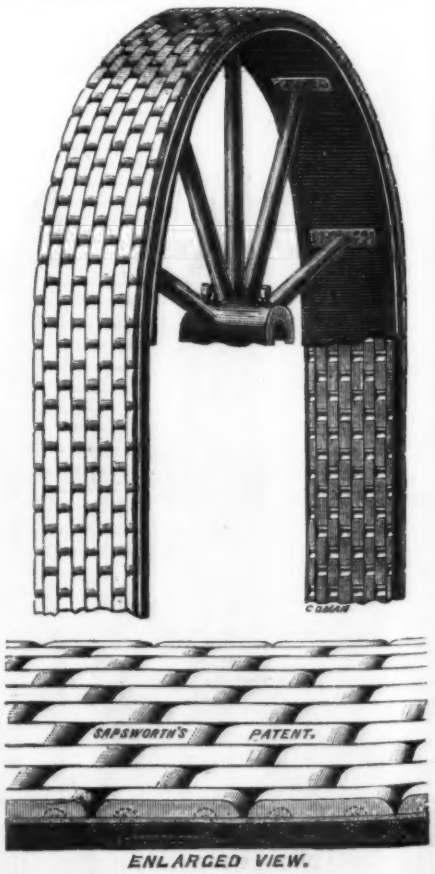
THE PERFORATED PULLEY.

MR. SHEPHERD, who is the patentee of these pulleys, conceived the idea that "slip" might be occasioned by a cushion of air, which was formed by the action of the running strap, and which was confined between the strap and the periphery of the pulley. Accordingly, as will be seen from our illustration, the rim of the pulley is perforated with a number of holes, which permit the confined air to escape, and so allows close contact to take place between the belt and the surface of the pulley. The holes are made in such number and diameters as are found most effective, the approximate speed of the pulley being taken as a guide in fixing this point. This, it is claimed, has resulted in an increase of power being being obtained from the same belts and pulleys; and it is also claimed that the maximum of engine power is regularly transmitted. We have been favored with copies of testimonials from users in all classes of trade, who unanimously agree as to the benefits derived; and if, as we have no reason to doubt, their statements are correct, we are furnished with another proof of the fact that the little things are of great importance.—*Textile Manufacturer.*



A WOODEN DRIVING BELT.

MANUFACTURERS of driving belts appear to have been determined for some time past to prove that if there is nothing like leather there are some things better than leather. They have not uniformly succeeded, but it must at least be admitted that some very excellent substitutes may now be obtained. Among them are cotton and camel hair, and to these must now be apparently added wood! At first sight this appears to be an extraordinary substitute for leather, but the exhibit of Messrs. S. E. Norris and Company, of Shadwell, London, at the Inventions Exhibition, London, includes samples of a very ingenious and practical application of wood for this purpose. It is illustrated



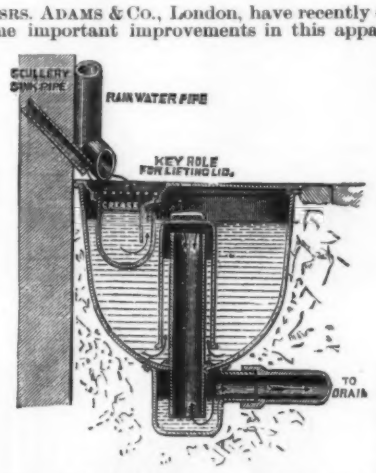
ENLARGED VIEW.

by the accompanying engravings, one of which shows the belt applied to a pulley, and the other an enlarged view indicating the method of construction. Links of wood are first cut from suitable timber, and these are then faced with leather, drilled and pinned together in the same manner as the now familiar leather link belting. Since wood does not expand or contract lengthwise of the grain with variations of humidity, the advantage claimed for it, "that these belts neither stretch nor contract," appears reasonable, and as the links are faced on their working side with leather, they evidently should drive as well as leather. It is now some years since it was shown at the Franklin Institute and elsewhere that "ventilated contact" between belt and pulley increased the power and added to the durability of the strap. As leather belts are ordinarily run, it is alleged that they, to a greater or less extent, float upon a film of air inclosed between the belt and the face of the pulley, and that consequently there is less grip between the two than there would be if the contact was ventilated in such a manner that the air could escape freely.

We think it may freely be admitted that at least some of the success achieved by link belts is due to the fact that they are sufficiently pervious to allow the air to escape, although we have not observed the fact to be claimed by many of the makers. Besides the advantages we have mentioned, the makers claim for it that it is cheap, strong, durable, easily put to work and maintained; that it runs straight and noiselessly, and equally well at high or low speeds in wet or dry places, and that the breaking strain is ten times the working strain. The inventor, Mr. Sapsworth, a member of Messrs. Norris' firm, informs us that they have had for the past eight months an 8 in. wood belt running at the rate of 2,800 ft. per minute, driving a machine which requires 12 horse power, and that it is as good as on the day it was started. Another wood belt 6 in. wide has been driving the machinery of their other factory and a power crane. Its speed is 1,000 ft. per minute; it has not been taken up since it was put on, and is now as tight as ever.—*Textile Manufacturer.*

IMPROVED SIPHON TRAP.

MESSRS. ADAMS & CO., London, have recently effected some important improvements in this apparatus,



by the use of which waste water, which would otherwise be of no value for flushing purposes, is collected and discharged automatically to the drain with great force, effectually scouring the pipes, preventing deposit of heavy matter, choking, and the formation of sewer gases. Hitherto considerable difficulty has been experienced from the constant choking of the siphon grease traps where used with water, etc. In this apparatus the small intercepting trap checks the entry of grease, etc., allowing water only to pass to the tank. The apparatus is so constructed that at any time the siphon may be removed, cleaned, and replaced in a few moments. The tanks are made in cast iron, either galvanized or coated black, and in stoneware. The galvanized are the best, in our opinion; they are indestructible, do not corrode, and not liable to damage in transit. The tank on becoming full immediately discharges itself by the siphon, delivering its entire contents to the drain. It then fills again, and the discharge is repeated.

THE KANSAS CITY CABLE RAILROAD.

FEW cities have had to contend with such topographical difficulties in the effort to get reasonable gradients for its streets as Kansas City, Mo., and few or perhaps none have ever gone to such enormous expense in proportion to their means for the purpose of smoothing off natural irregularities. Without grading down the whole city some 200 ft., however, it was not possible to avoid excessive grades on the most used thoroughfare of all, that descending from the city proper to the railroad yards and manufacturing works of the flat below, and many of the thoroughfares of the city proper were inconveniently steep. The cable system, therefore, was peculiarly adapted to the necessities of the situation, and one presenting some interesting features has recently been constructed, of which we illustrate the most striking feature, the descent from the bluffs.

The incline down the bluff is a grade of 18·3 in 100, and descends from an elevation of 191 ft. to the center of the main span (185 ft.) across the yards of the Union Depot. The iron work consists of eleven spans of the following lengths, beginning at the bottom: 65, 185, 67, 29, 45, 46, 47, 46, 46, 47, and 47 ft.

At the end of the last span the cable leaves the open work of the viaduct, and enters a concrete subway below the street.

This cable road is peculiar in having a duplicate cable, so that repairs or renewals can be made without any interruption of travel. In fact, it has a duplication of machinery along the whole line, so that if an accident occurs it can be remedied without any loss of time. There are two carrying pulleys side by side to support the cables in every pulley-pit, the pulleys being 35 ft. apart longitudinally. At the extreme ends of the railway, where in the ordinary cable road there is one sheave 12 ft. in diameter, in the Kansas City road there are two. In the engine-house also there are two independent engines and two sets of driving machinery complete. No other plant in the United States makes these provisions.

Some serious engineering difficulties presented themselves, one of the most serious of which was at the foot of the bluffs. In locating the foundations for the wrought iron supports for the viaduct, the discovery was made that a local movement in the limestone ledge was taking place. When the large mass of loose earth and rock at the base of the bluff had been removed, the limestone ledge in question was exposed, and it was found that a stratum of soapstone and bituminous shale 18 ft. in depth was rapidly crumbling, and allowing the limestone above to descend. The remedy applied to this annoying difficulty was ingenious and interesting. The rock ledge was first thoroughly cleaned of all extraneous material, and then its cracks and fissures were filled with a liquid cement grout made from German Portland cement. The water and moisture which had served the purpose of a lubricant, and thus caused the "crumbling," was by this means excluded, and the cause being removed, the evil effect ceased.

The sewers encountered also caused much difficulty, so that the simplest remedy was found to be to build a new sewer under the track for almost its entire length, and let the city sewers encountered at each street crossing run into it.

The cable is 1¼ in. diameter, of Swedish iron wire, capable of resisting a strain of 30 tons. The total length of both cables is 44,000 ft., and it is expected that they will have to be replaced every eighteen months of continuous service. The weight of both cables is about 56 tons.

Although the changes of grade are unusually sharp and frequent, the natural sag of the cable is sufficient to hold it down upon the pulleys except at two or three points, where sharp depressions occur. At these points depression-pulleys are placed which hold the cable down, and, when the grip passes, the cable is pressed down 6 in. below these pulleys; thus the grip avoids contact with them. The weight of the cable itself is 2½ lb. per lineal foot, which with the ordinary tension and an average number of grips, with their loaded cars attached by it, causes a deflection between the carrying-pulleys, 35 ft. apart, of about 2 in. The average tension on the cable required to barely do the work is about 4 tons, the cable leaving the engine-house with a strain of about 1 ton, and returning to it with about 5 tons.

The total length of the road is now 2¼ miles; but it is expected to extend it one mile eastward on Independence Avenue and still another mile on Ninth Street the present summer. An extension to and into the city of Wyandotte, Kan., across the Kansas River, is also contemplated.

The maximum grades on the several cable railroads of the country compare as follows, that on the Kansas City line being the heaviest:

Clay St., San Francisco, 16 in 100.
California St., San Francisco, 18 in 100.
Suter St., San Francisco, 8·7 in 100.
Geary St., San Francisco, 9·8 in 100.
Ninth St., Kansas City, 18·3 in 100.
State St., Chicago, about level.

The engine house is a substantial brick structure of two and one-half stories, 90 × 144 ft. The total boiler capacity is 600 horse-power, which is considered amply sufficient for all demands.

The grip attachment is operated from the end of the car instead of the center (as in all other lines), and the passengers are thus no longer interfered with and discommoded, while the carrying capacity is increased. It consists of three parts: the upper or crank, the middle or shank, and the lower or jaws. The crank and shaft giving motion to the jaw of the grip are connected at one side with the levers of the grip wheel in the cab, and also connected with the central and moving part of the shank, which has a vertical motion. The moving part of the shank is also connected with the movable and horizontal upper jaw of the grip. The shank is made from rolled steel, and the jaw of cast steel lined with brass, reducing the wear on the cable to a minimum. The lower jaw of the grip is stationary, having two rollers placed vertically at each end of the jaw.

When it is desired to start a car, the grip wheel in the cab is turned to the right, which forces the movable upper jaw (17 in. long) down on the cable resting on and rolling over the pulleys in the lower jaw of the grip. The pressure forces the rollers down a limited distance with the cable, as they are supported by flexible journals; the brass in the grip takes hold of the cable under the pressure of the grip-wheel, and the car moves. If it is desired to stop the car, the grip-wheel is turned to the left, thus raising the movable upper jaw from the cable. The pressure being released, the small pulleys in the lower jaw spring upward slightly, and support the moving cable.

It does not matter how often stops are made, the cable never leaves its position between the grip's jaws—it is either gripped by the jaws or riding on the pulleys in the lower jaw. It is, however, conducted out of the grip when it is necessary to change the car from one track to another, and in passing over the vault on the south track at the engine house. The cars are carried over this distance, which amounts to 40 ft., by momentum acquired before reaching the vault. This occurs on the south track only.

Mr. Robert Gillham was Chief Engineer of the road, and Mr. Victor Spangberg First Assistant Engineer.

A road somewhat similar to the one described, but differing in important respects, is now in process of construction at Hoboken, N. J., to ascend to the bluffs (the Palisade ridge) back of the city.—*Railroad Gazette.*

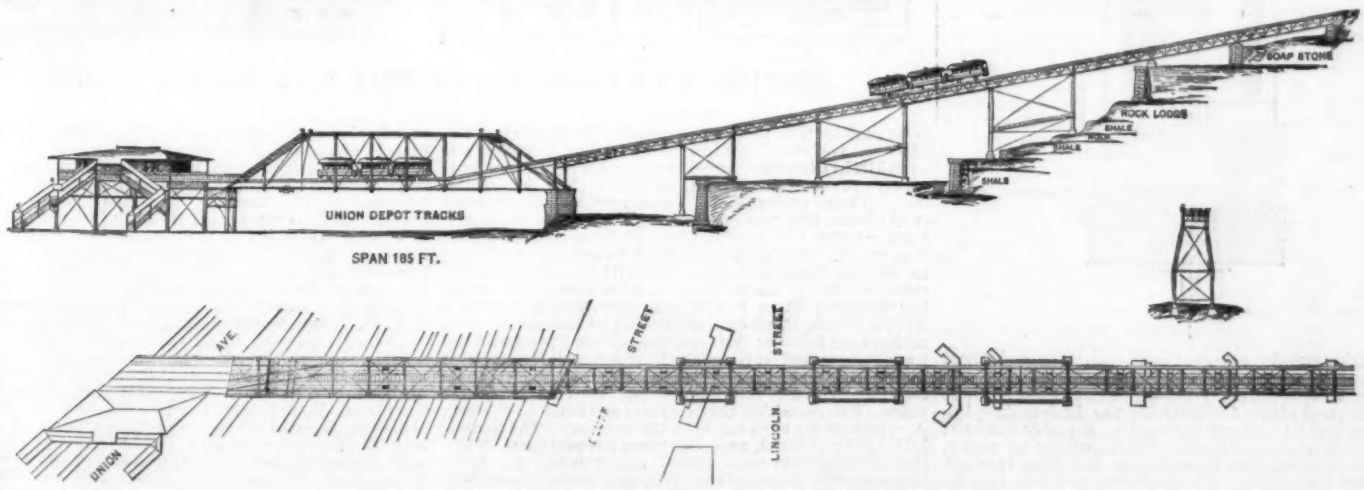
SINKING THE CYLINDERS OF THE TAY BRIDGE BY PONTOONS.*

By Mr. ANDREW S. BIGGART.

ONE of the most common forms of foundations now adopted on which to build the superstructure of a modern bridge is the cylinder. But, as the foundations are often in positions difficult to get at, and, when there, to remain at, owing to causes such as the rise and fall of the tide, rapidity of the current, storms, etc., a difficult problem in connection with the building is often, How are the cylinders to be sunk? One of the easiest, and at the same time most sure, methods now in vogue is to build a wooden stage around the place where each cylinder is to be sunk, and from this as a working platform lower, dig out, concrete, and carry them up to the desired height. Some cylinders are of sufficient capacity to float themselves with perfect safety to their respective positions, as well as be made to carry all the sinking apparatus and platform necessary to regulate their descent into their final resting place. Or again, if we drop to the smallest form of cylinder, we would instance the screw and the hollow pile, the former of which is sent home by the simple, though sometimes difficult, process of screwing into the ground, while the latter is driven. While work can and is being done every day by methods similar to these, it is readily understood that much is done, especially if a stage has been constructed, which requires to be undone with a consequent loss of time and money. To use the old method of staging for such a work as the New Tay Viaduct would have required almost a forest of timber for this alone, and, owing to the great depth of water, the work would have been both tedious and expensive.

Before proceeding to sketch the novel method which has, however, been adopted, let us look at the primary conditions which must necessarily be fulfilled by whatever form of platform is used: (1) There must be a working platform, on which can be placed cranes and other machinery; (2) the platform must be high enough to permit of work being conducted from and upon it at all states of the tide; (3) it should also be capable of being removed speedily from one position to another. These primary conditions, enhanced by many other

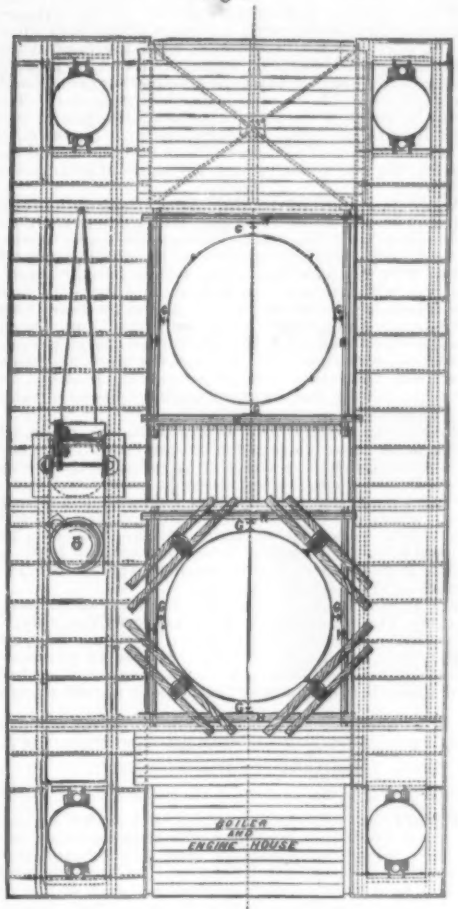
* Paper read before the Institution of Engineers and Shipbuilders in Scotland, April 28.—*The Engineer*



THE KANSAS CITY CABLE RAILROAD.

advantages, are practically realized in the pontoons designed by Mr. Arrol, and now used successfully by him in sinking the cylinders of the New Tay Viaduct. The pontoons used, of which there are four, are all made up of tanks, for the sake of convenience, which are rigidly fastened together in the form of a rectangle, and they vary in size from 56 ft. by 36 ft. 6 in. by 6 ft.

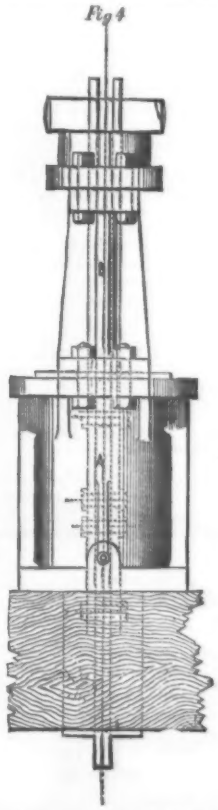
Fig. 1.



deep, as in the smallest, to 81 ft. by 66 ft. by 7 ft. deep, as in that of the largest. We propose to confine our description to one of these, as all are the same in principle, varying only in some of the details.

Fig. 1 presents a plan of No. 2 pontoon. You will observe there are two main tanks running the whole length of the platform, connected together by one small tank and several main cross girders, the full depth of the tanks, as well as the top and bottom outer cross girders. In both of the main tanks there are two

Fig 4



rectangular openings, one at each end. Through these the legs are passed which are used for raising and lowering the platform. To the tanks are fixed at these openings steel plates for carrying the hydraulic cylinders required to perform this action. Equally from the center, and at the distance of 26 ft., center to center, the large cylinders are lowered, one at a time, through the center openings in the platform, and this, too, by special hydraulic machinery, being guided in their descent by the vertical guides, G, which in their turn are attached to the cross girders, HH, fixed at the top and bottom of the tanks. The cross girders are only temporarily fastened, so that in the event of the platform being raised somewhat out of position they can be shifted, and with them the guides, thus making it practicable with almost a minimum of labor to lower the cylinders in their true position, even although the pontoon has been pitched slightly out of place. On one of the main tanks there is fixed a crane which is used for lifting material on to the platform, and also for excavating by means of mechanical diggers the sand and earth within the cylinders. In the small connecting tank is placed a boiler and engine, used for driving the hydraulic pumps, working windlass, etc., as may be required.

Other machinery and gear, such as portable boiler and engine, centrifugal pumps, capstans, bollards, fairleads, workshops for the men, all find a place on this sometimes floating staging, at other times stationary and high out of the water.

Before this description can be of much practical value it will be necessary to describe more in detail the principal parts of the pontoon, and the mode by which it

Fig 3.

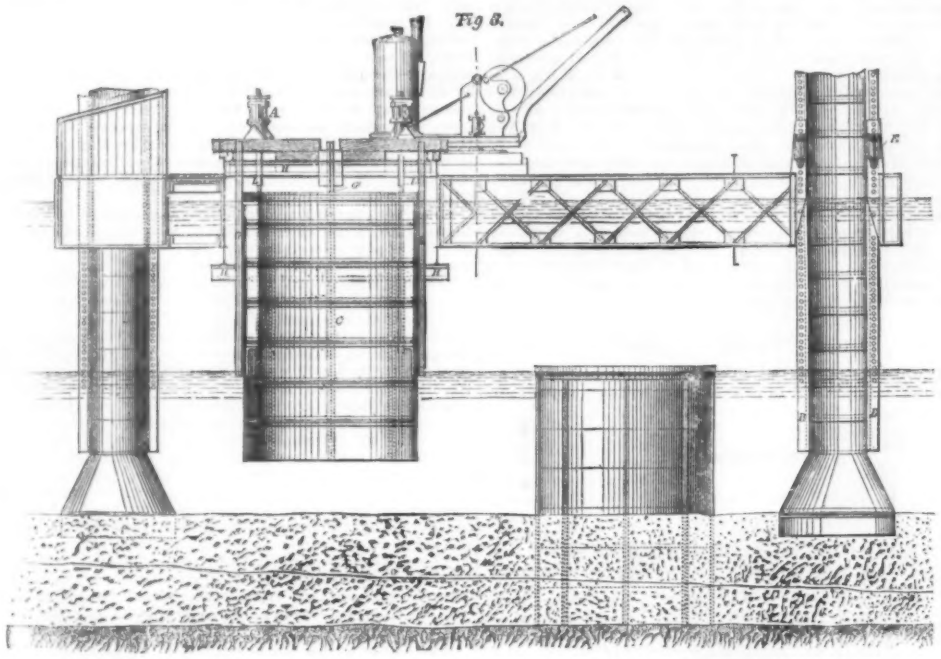
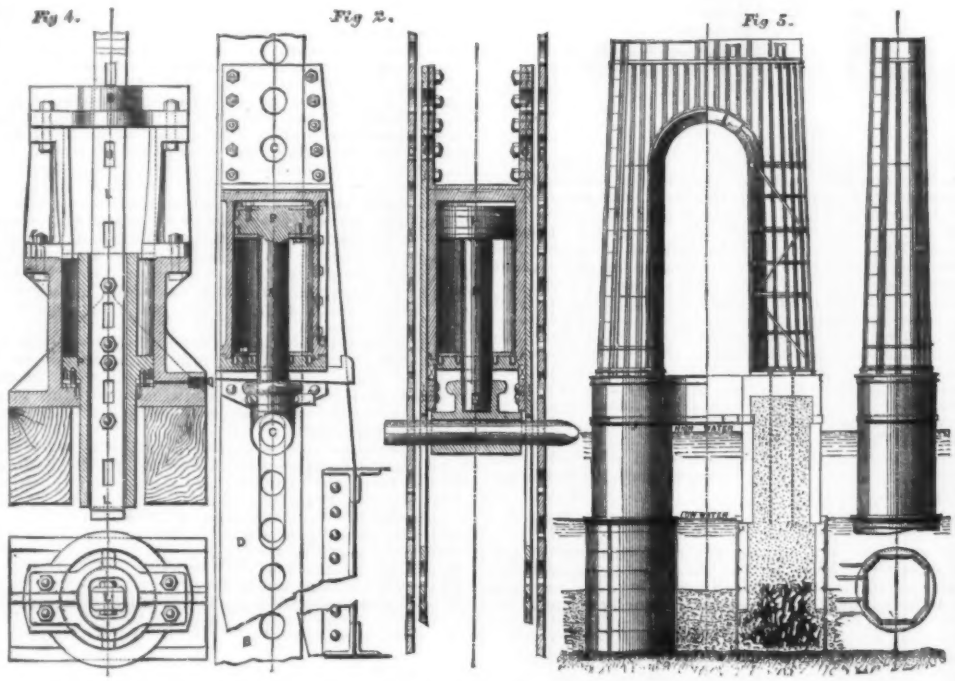


Fig 4. *Fig 2.* *Fig 5.*



SINKING THE CAISSONS OF THE TAY BRIDGE PIERS.

is wrought. The method of raising and lowering the platform is shown by Figs. 2 and 3. The four legs are each 5 ft. in diameter, and of a conical shape at the bottom, to prevent the ground on which they rest being scoured from underneath. On it are fixed four heavy steel plates, BB, two on each side, about 16 in. apart, having holes, CC, passing through them, spaced about 6 in. apart. Sliding within these two plates, but fixed to the platform, are other two, DD, having holes the same size and pitch as in the outside plates, and carrying between them a hydraulic cylinder, E, provided with a piston, P, piston rod, R, and crosshead, I. The action is as follows: Suppose the piston, P, to be at the top of the cylinder; through the crosshead, I, and outer plates, BB, a steel pin is passed; when water is admitted, the cylinder, E, is forced up, because the outer plates, BB, on which the pin rests are fixed to the leg, A, which in its turn bears on the ground. The plates, DD, are thus lifted, and with them the platform. When the cylinder has been raised about 6 in., the holes through the inner plates, DD, and outer plates, BB, are in line. Into one of these is now passed another steel pin. If the water in the cylinder, E, is allowed to go free, the platform will now hang on the pin just inserted, and allow the first to be withdrawn. The piston is now forced to the top of the cylinder, and the first pin being again inserted, all is ready for another lift. From this you can readily perceive the only limit to the height to which the platform may be raised is the length of the leg and its accompanying plates. In lowering the platform this action is simply reversed. Both cylinders at each leg are wrought at the same time, and, if convenient, the others at the remaining corners of the platform. The large foundation cylinders, two of which are in each pier, are lowered into position by the hydraulic apparatus shown by Figs. 1, 3, and 4. Each of these cylinders, including an inside brick ring, which must be built before being lowered into position, weighs about 50 tons, varying less or more according to the depth to which it is to be sunk. The hydraulic cylinder and links for lowering these foundation cylinders are shown by Fig. 2. Figs. 1 and 3 show the manner in which these are wrought. C is the cylinder to be lowered; A the hydraulic lowering cylinder; P the piston and hollow trunk through which are passed the steel links, L, these being single and double every alternate length, and through all are cottar holes about 10 in. apart. B is a bow, fixed on to and over the hydraulic cylinder, A; through it the links are also passed, they being in short lengths, and attached to one another by means of bolts. At the bottom of the cylinder, C, these links are firmly fixed to a plate, which, in its turn, is securely bolted to the cylinder. The action in lowering is as follows: Suppose the combined piston and trunk, P, is almost raised to the top of its stroke; by admitting water through a cock at Q, a cottar is able to be inserted through the hole, H. Upon water being again admitted, the links are raised, and with them the cylinder, C, thus relieving the top cottar—presently resting on the bow—which is then withdrawn and inserted in the first hole higher up. The water being now allowed to escape, the piston, P, and links, L, with the large cylinder, C, attached, descend till the top cottar again rests on the bow, B. The lower cottar is then free to be withdrawn and inserted in the first hole higher up, and this done we are ready to begin a new stroke, and so continuing the cylinder, C, is gradually lowered till it reaches the river bed. Four of these hydraulic cylinders are em-

ployed in lowering one foundation cylinder. The water for all the hydraulic machinery is obtained from the pumps already mentioned. The diggers used are of various types, but principally consist of those with hinged automatic doors, which are open when the digger is dropped into the ground, and closed by links in the act of withdrawal. These are used principally in excavating the sand and other soft materials; others having hydraulic cylinders for opening and closing strong toothed doors, in order to tear and bring away the softer rocks and hard clays, have been used, but to no extent. In some cases a centrifugal pump has been utilized to great advantage for taking out the silty sand within the cylinders. The main suction pipe has two inlets, to each of which is attached a flexible rubber pipe. While the nozzle of the one inlet is being held to the sand by a diver, the other is loose and sucking in clean water. By using this precaution the pump seldom gets choked, and with some kinds of deposit this method is found to give excellent results.

After this preliminary description you will readily follow the mode of working the pontoon during the sinking of a pier. The first thing necessary to be done is to float out the pontoon as nearly as possible to its true position, immediately over where the cylinders are to be sunk. It is taken to its place by means of the crane already on it, acting as a windlass, the ropes and chains being fastened to buoys and the piers of the old bridge. Placed in position, it is only the work of a few minutes to drive away the temporary supports on which the legs are resting—the pins at this time being all removed—when they gradually sink to the bottom. The hydraulic apparatus used in raising the platform—already described and shown in Fig. 4—is now brought into requisition, and made to lift it to the desired height. This is generally attained when the bottom of the pontoon is about 2 ft. under high water level. The best, and occasionally the only time the pontoon can be brought into position, before being raised, is at high tide. It is the best because the platform is about as high as it requires to be, and occasionally it is the only time, on account of the depth of water required to float it in. Anchors and chains are now called into requisition to assist the legs in keeping the platform steady, which, by the way, is found to be remarkably easy, even in the roughest weather. When standing on the platform, during a high wind, and carefully watching the movement at high tide, when the waves are dashing against it, the oscillation is found to be very slight, even with both these adverse circumstances to its steadiness in play. All done, we have a fixed platform, above the influence of the tide, and at the same time in the best attainable position relative to the pier at which work is about to be commenced. Upon the platform is also placed all the necessary apparatus for the lowering, sinking, and building of the cylinders, material, of course, excepted. The cylinders are now built over one of the central openings of the platform, being brought in complete rings, for convenience in handling, as part of the fixing together has to be done while they are thus being built in position. As section after section of iron is added—within—on the inner side is built a ring of brick in cement, thereby increasing the weight, which assists during the process of digging to sink the cylinder and also keep it in form, as well as fulfilling the primary object of its being there, namely, to insure the safety of the structure in the event of the iron being corroded away. While the rings are in course of being added, all at the same time are lowered by the hydraulic apparatus already described till the cylinder reaches the river bed. The digger is now set to work, and gradually excavates the material from within the cylinder, and thereby makes a way for it to settle down into the ground, and this is continued until it reaches its proper depth. Although apparently easy and simple on paper, the difficulties in the way preventing the desired end being attained are sometimes enormous; for example, you may come on a bed of bowlders—this is found in many piers, being the protecting rubble of the old bridge piers—or even one large one, say one-quarter within and the remainder outside of the cylinder, or get into clay so hard that the digger can barely cut into it, and yet so leaky as to make it impossible to pump the cylinder dry. Or there may be difficulties, the causes of which, if known, could be as easily counteracted and overcome as was the case when the sand saddened within the cylinder during the ebbing of the tide, on account of the water being higher within than without; the digger in these circumstances brought up only a small quantity at a time, nothing to be compared to what was done when the water was kept a little lower within than without. This is easily accomplished by the artificial means of pumping, the effect of which is to cause a little water to be constantly leaking through the sand into the cylinder, thereby keeping it loose, and consequently making it easy to be dug into. At other times the diggers are completely useless for excavating the material within the cylinders; a good alternative—if at all possible—in a case of this kind is to force the cylinder down by piling on weights, till it becomes practicable to pump it dry, after which it can be dug out by hand. Before this has been accomplished, in some cases it has been necessary to add as much as 400 tons of artificial loading to some of the 15 ft. diameter cylinders. If the cylinder cannot be made water-tight, then in a case of this kind resort has to be had to divers.

When a cylinder has reached the desired depth, and provided the bottom is satisfactory, filling in with concrete is commenced and continued till it reaches the top of the ironwork. The material for making the concrete—gravel and cement—is in most cases lowered from the old viaduct, which is only 60 ft. to the eastward, and runs parallel with the new, except a short piece at the ends. The gravel is emptied out of the trucks into a chute resting on the pontoon platform, and is there mixed and afterward thrown or lowered into the cylinders, as the case may require. The second cylinder having been placed in position in a similar manner to the first, the platform is now lowered and at high tide floated away over the top of the now sunk cylinders, the tops of which are only visible at extreme low water, thus leading the uninitiated to suppose little has been done because little is seen. Cast iron weights are now built on girders above the cylinders for the purpose of testing the sufficiency of the foundation. Sufficient weight is laid on to cause a pressure of five tons per square foot on the whole area under the cylinders. If they sink at all, these weights are allowed to remain until all indications of such are stopped, after which they are transferred on to the next set by means of a wire cable or barge. It is here worthy of notice that the test load placed on the piers is 33⅓ per cent. in excess of the weight that would be brought, although the two lines were fully loaded with trains. On the removal of the weights, temporary caissons are fixed to the permanent cylinders by bolts, and pumped dry. The remaining blue brick, outer shell, concrete, and stonework above low water is then executed. Twenty feet down into this are built the holding-down bolts, sixteen in number, in each pier, all 2¼ in. diameter. The caissons are removed, and afterward the connecting piece between the cylinders and the remainder of the pier is built up to and underpinned beneath the iron base on which the wrought iron superstructure rests. Process is thus going on at several piers at one and the same time: (1) The pontoon, lowering, digging, and concreting; (2) testing the value of the foundations; (3) building under high-water within the temporary caissons; (4) finishing remainder of pier to underside of ironwork. This, again, is but the startiug point from which the iron superstructure, as shown in Fig. 5, begins to rise—in stages also—to be followed by the placing of the girders and flooring, on which, finally, the track is laid.

Although the advantages gained by using pontoons such as those described are apparent to all, it is at the same time evident they could not be used to advantage, except on works of some magnitude, where, for instance, there are a goodly number of piers to be put down, and also difficulties to be overcome, for grappling which they are peculiarly suited. The new Tay Viaduct furnishes such work and difficulties. The pontoons on the Dundee side sank and concreted one complete pier—of two cylinders, 10 ft. diameter each—per week, for nearly two months on end, the greatest difficulty to contend with being the shallowness of the water in which it had to work. The depth to which each of these cylinders is sunk varies from about 16 ft. to 26 ft. under the bed of the river.

Such is a very brief *resume* of the foundation work, and the mode by which it is being accomplished at this viaduct at the present time. Time alone will tell, when the results are balanced, if the decision was altogether wise which fixed on this novel method of carrying out a vast undertaking.

[Concluded from SUPPLEMENT No. 457, page 7294.]

THE FORTH BRIDGE.*

By B. BAKER.

As it is impossible to produce the working drawings of the bridge on the present occasion, a short tabular statement of some of the leading features may be desirable.

	Tons.
Steel in main cantilevers	40,000
Steel in center girders	1,600
Steel in viaduct approach	2,800

Cantilevers, 680 ft. projection; 343 ft. and 40 ft. deep.

Bottom member of cantilever, a pair of tapering tubes:

Distance apart centers at piers	120 ft.
Distance apart centers at ends	31·5 ft.

Tube at piers, 12 ft. in diameter, 1¼ in. thick, 830 sq. in. area.

Tube at ends, 5 ft. in diameter, ⅜ in. thick, 120 sq. in. area.

Top member of cantilever, a pair of tapering box lattice girders:

Distance apart centers at piers	33 ft.
Distance apart centers at ends	22·25 ft.
Girder at piers, 12 ft. by 10 ft	506 sq. in. net area.
Girder at ends, 5 ft. by 3 ft	60 sq. in. net area.

Columns over piers, 12 ft. diameter, 368 to 468 sq. in. area.

Diagonal struts (tubes), 8 ft. to 3 ft. diameter, 198 to 73 sq. in. area, and 337 ft. to 74 ft. long.

Diagonal ties (box lattice), 8 ft. to 3 ft. deep, 163 to 67 sq. in. net area, and 327 ft. to 82 ft. long.

Horizontal wind bracing (box lattice), 11 ft. to 3·5 ft. deep, 88 to 20 sq. in. area, 142 ft. to 40 ft. long.

Vertical wind bracing (box lattice), 4·75 ft. to 2·5 ft. deep, 84 to 28 sq. in. area, 160 ft. to 60 ft. long.

Central girder, 350 ft. span, 51 ft. and 41 ft. deep; bottom members, 32 ft. apart centers, 142 sq. in net area; top members, 22·25 ft. and 19 ft. centers, 139 sq. in. gross area.

Internal viaduct, lattice girders with spans of 39 ft. to 145 ft.

Floor, buckle plates and trough girders.

Wind fence, close lattice work, 4 ft. 6 in. high.

Viaduct approach, lattice girders, under rails continuous over two 168 ft. openings, 22·5 ft. deep, 16 ft. apart; floor and wind screen as for internal viaduct. Masonry piers 25 ft. by 8 ft. at top, and 50 ft. by 20 ft. at base.

Rolling load: (1) trains of unlimited length on each line of rails, weighing one ton per foot run; (2) trains on each line made up of two engines and tenders, weighing in all 142 tons, at the head of a train of sixty short coal trucks of 15 tons each.

Wind: A pressure of 56 lb. per square foot, striking the whole or any part of the bridge at any angle with the horizon, and acting square or obliquely upon an area equivalent to twice the plane surface of the front girders, with a deduction of 50 per cent. in the case of tubes. The total wind pressure so derived amounts to 2,000 tons on the 1,700 ft. span, and 7,900 tons on the whole superstructure included between the two cantilever end piers. The following table shows the magnitude and intensity of the heaviest resultant stresses in tons on some of the principal members from dead load, live load, and wind, distributed as already described.

Owing to the batter of 1 in. 7¼ of the main girders and the adoption of double piers, not merely at Inch Garvie, but for the main piers on either side of it, the calculation of stresses involves some interesting and complicated problems. It is fortunate that from the nature of the ground no unequal settlement can occur in the foundations, or some of the stresses would be indeterminate by reason of the double piers, which, I may add, were not a feature of the original design.

At the center cantilevers any unequal loading is supported by the double bracing between the piers at Inch Garvie, but at the north and south cantilevers the support is twofold, namely, the resistance of the bracing and the pull on the holding-down bolts at the cantilever end pier. The first problem that arose, therefore, was to ascertain how much of the load would be supported by each of these reactions.

	Dead.		Live.		Wind.		Total.	
	Gross Stress.	Stress per sq. in.	Gross Stress.	Stress per sq. in.	Gross Stress.	Stress per sq. in.	Gross Stress.	Stress per sq. in.
Bottom member	2282	2·8	1022	1·2	2920	3·5	6224	7·5
Top member	2253	4·4	997	2·0	544	1·1	3794	7·5
Vertical member	1550	3·3	705	1·5	1024	2·2	3279	7·0
Diagonal struts	802	4·1	167	0·8	414	2·1	1383	7·0
Diagonal ties	754	4·6	186	1·2	194	1·2	1134	7·0
Hor. wind bracing	80	0·9	5	0·1	265	3·0	350	4·0
Ver. wind bracing	42	0·5	169	2·0	108	1·3	319	3·8
Central girder top	337	2·4	303	2·2	182	1·4	822	6·0
do bottom	330	2·3	301	2·1	247	1·8	878	6·2

But the weight of each part was not known, and in a structure of this magnitude it required to be ascertained with accuracy. This could only be done by the method of trial and error, and as the stresses produced by the weight of the structure itself are very considerable, and as the secondary bracing is an important item, detailed drawings had to be made and carefully measured several times before the stresses could be determined. The inward slope of the cantilever gave rise to forces of sensible amount from the component of the vertical forces square to the plane of the cantilevers. A much more difficult problem, however, was presented by the stresses produced by wind. Thus, for example, a force acting horizontally on the cantilever near the 350 ft. girder, and at right angles to it, produces at the main pier a downward pressure on the leeward side and an upward action on the windward side, together with a twisting action, and vertical and lateral pressures on the cantilever end pier. All these forces had to be traced through the different members and bracings, and the same had to be done for a wind force acting as a moving load at every point of the cantilever. It was also essential to consider the wind as blowing not only at right angles to the line of the bridge, but also at such other angle as would impose on each member the greatest amount of stress. It will be readily seen that the stresses produced by wind are very severe, and, therefore, exactness was required in order that no part might be unnecessarily heavy, nor on the other hand be strained beyond the allowed amount. After all the stresses as a framework structure arising from the dead load, a traveling train, and from wind had been ascertained, a new set of problems arose, chiefly from the magnitude of the work and the weights of the different members themselves, which cause local stresses of considerable importance in some instances.

An all-important point was, of course, the stress per square inch admissible upon the several tension and compression members. The only limit practically imposed upon us by the Board of Trade was that the stress should not exceed one-fourth of the ultimate strength of the steel, without reference to the question of the relative proportions of live and dead load or the character of the stress. In settling the sectional areas we did not bind ourselves to any formula derived from Wöhler's or other experiments on the fatigue of metals, but considered each member separately and had reference to the whole of the circumstances, including the character of riveting and other details of construction. As many competent engineers are of opinion that the rational way of proportioning structures is to assume varying ultimate resistances of the metal for the different proportions of dead and live load, and adopt a uniform factor of safety of 3, we tested the actual areas of the Forth Bridge members by the following rules, and found in all cases an excess on the requirements:

a. For a constant load assume the ultimate tensile strength to be 30 tons per square inch.

b. For a load varying from *nil* to a maximum assume the strength to be 20 tons per square inch if the alternation of stress is frequent, and 22·5 tons if it is seldom, as in the case of a hurricane.

c. For alternate tension and compression assume the ultimate strength to be 10 tons if frequent and 15 tons if seldom.

The above apply to tension members, and are to be divided by 3 for the working stress. For struts the working stress equivalent to the above, from the results of my own experiments and from other considerations, I take to be 40 per cent. of the stress causing first flexure, as given by the following empirical formulæ:

$$f = (0{\cdot}44 - 0{\cdot}002\,r)\,(t + 18) \text{ for tubes}$$
$$f = (0{\cdot}40 - 0{\cdot}004\,r)\,(t + 18) \text{ for lattice}$$

where r = ratio of length to diameter and t = tons per square inch, as set forth in paragraphs *a*, *b*, and *c*, but increased in all cases in the ratio of 34 to 30, which are the specified minimum strengths of the steel used for compression and tension members respectively.

I have no doubt that any structure proportioned by the above rules would have an ample margin of safety, but as already stated the stresses in the case of the Forth Bridge are lower than indicated. The diagram of stresses shows that the lower tubular member is the most affected by wind, and, in fact, under the conditions assumed the leeward tube does the work, and the windward is almost relieved of stress. Looking at the huge 12 ft. tubes as they now lie at the Forth Bridge works, with their ten longitudinal T bars 12 in. by 7 in. by ⅞ in., having double angles riveted to the web of the T, and with annular stiffeners every 8 ft., certainly nothing could appear better adapted to resist stress and fatigue, and I should not feel the least anxiety if they were subject to double the stress which will ever be imposed upon them. I may add that the preceding formula for struts is based upon my experiments with steel ranging from 26 to 56 tons in tensile strength, and fairly represents the average results, though in this instance, as in all others where columns are concerned, individual experiments differ rather widely, owing to initial stress, unequal bearing, or other cause. In proportioning the riveted joints of the tubes and other members, the shearing area is generally made one and a half times the net sectional area of the plates con-

* Paper read before the British Association at Montreal, 1884.

nected if in tension, and half that for planed and butted joints in compression only.

In my first paper I said that the maximum wind pressure upon the 1,700 ft. span had been assumed to be equivalent to a pressure of 56 lb. per square foot upon the double surface, and I regretted that such assumption necessarily involved many matters of pure conjecture, which rendered it impossible to state with precision what factor of safety would belong to the Forth Bridge. The same remark of course applies even now with equal force to every other bridge, because there exists a lamentable lack of data respecting the actual pressure of the wind on large structures. Mr. Fowler and I have spared no pains during the past two years to contribute something to the general fund of information, and other engineers, doubtless, are experimenting, for experiments, and not speculations, are wanted. We have had now for two years, on the island in the middle of the Forth near the center pier of the bridge, three wind gauges or pressure boards; the large one, 300 square feet in area, is fixed square to the east and west winds, and of the two small ones of 1½ square feet area, one is fixed as above, and the other is free to swivel square to the wind in any direction. When speaking at the Institution of Civil Engineers on the subject of wind pressure, previous to the erection of these gauges, I ventured to prophesy that, contrary to the opinion of many, the large board would show a smaller average pressure per square foot than the small ones. I have summarized the readings of the gauges for the past two years, and find them to fairly bear out my anticipations. In preparing the following table, the mean of all the readings of the revolving gauge between 0 lb. and 5 lb., 5 lb. and 10 lb., etc., have been taken, and the mean of the corresponding readings at the same time of the small fixed gauge and of the large fixed gauge for easterly and westerly winds have been set forth opposite.

Revolving Gauge.	Small Fixed Gauge.		Large Fixed Gauge.	
Mean Pressure.	Easterly.	Westerly.	Easterly.	Westerly.
lb. lb.	lb.	lb.	lb.	lb.
0 to 5 3·09	3·47	2·92	1·9	1·9
5 " 10 7·38	4·8	7·7	2·04	4·75
10 " 15 12·4	6·37	13·2	3·54	8·26
15 " 20 17·06	7·4	17·9	4·55	12·66
20 " 25 21·0	12·25	22·75	5·5	19
25 " 30 27·0		28·5	8·6	18·25
30 " 35 32·5		36·5		21·5
Above 35 (One observation only above 32·5.)		41·0		25·25

I do not myself, nor does Mr. Fowler, place implicit faith in the registrations of our own or anybody else's anemometers, although we test the working of the gauges in the most careful manner; but at the same time I think it is pretty well established by our two years' experiments, that the effective pressure per square foot on a large and comparatively heavy board averages only about two-thirds of that indicated by an ordinary light anemometer. It will also be noticed that the heaviest gales have been from the west, and that the revolving gauge then indicated much the same as the fixed gauge. Some critics were of opinion that our 300 ft. gauge would be of little use, as it could not swivel square to the wind, but remembering the experiments made with a fan blast on oblique plates, which showed that the resultant pressure was normal to the surface, I felt sure that having reference to the prevailing winds swiveling was of no practical importance at the Forth, and the results justified my anticipations.

The two heaviest gales occurred in the early morning of December 12, 1883, and January 26, 1884, respectively. On the latter occasion much damage was done throughout the country, and there was conclusive evidence from the extent as well as the intensity of the storm that it was a very exceptional one in character. At Inch Garvie the small fixed gauge was reported to us as registering 65 lb. per square foot, but on inspection I found the index pointer could not traverse further, or it might, perhaps, have indicated much higher. At Valencia very strong squalls covering short periods were stated to have attained a rate of upward of 150 miles an hour. At Holyhead lengthened squalls of 120 miles and short squalls of higher rates were reported. At Alnwick we were told that several instances of 10 miles in five minutes, or 120 miles an hour, and squalls of 150 miles occurred. Now if we assume, as is common, the pressure of wind to be equal to $0{\cdot}005\ V^2$, and accept the velocity of 150 miles as correct, we shall have to believe that pressures of 112 lb. per square foot were reached at Valencia on the west coast of Ireland and at Alnwick on the east coast of England on the 55th of January last. I confess I find it much easier to believe that the records of anemometers as at present obtained are utterly misleading and valueless for all practical purposes. I entirely mistrusted our own 65 lb. record, even before I knew that the index was at the end of its travel. On finding out the latter fact, however, I experimented with the gauge, and finally in the presence of the inspecting officers of the Board of Trade, made it register 65 lb. by the sudden application of a pressure not exceeding 20 lb. The momentum of the light index needle, and not that of the pressure plate, which was bridled back, sufficed to cause the error.

I look upon the record of 65 lb., therefore, as valueless so far as regards the specific maximum pressure attained during the great storm, but of considerable value as evidence that the highest pressure, whatever it might have been, partook of the character of a smart jerk of too instantaneous duration to affect a structure of any size or weight. From the records generally, and from my own watching of the movements of the three gauges, I have come to the conclusion that uniform velocity and pressure in a wind, whether it may prevail or not at cloud heights, can never obtain near the surface of the earth or in the neighborhood of any bridge or other structure capable of causing eddies. Unsteady motion must be the rule in air as in water, and the threads of the currents moving at the highest velocity will strike an obstruction successively rather than simultaneously, so that the mean pressure per square foot on a large area must be less than that on a small surface from that cause alone, irrespective of possible differences in the partial vacuum at the back of the planes.

In the spring of this year, when running into Dublin harbor during a heavy broadside gale, I took occasion, when in still water but in the full blast of the wind, to measure the heel of the vessel, and from her elements to calculate subsequently the mean pressure required. My pressure board in this case was about 6,000 square feet in area, and the deduced mean pressure was 12 lb. per square foot. From other data I estimated the corresponding anemometer pressure at fully double the preceding amount, and this was perfectly rational, because the vessel kept steady at a constant heel, while heavy local gusts of very small area struck different parts of her in a distinctly recognizable manner. In short, the large area and heavy mass of the hull equalized the jerky action of the numerous small blasts of high intensity, and a similar action doubtless takes effect in ordinary railway structures, and will to a still greater extent in such a large and heavy structure as the Forth Bridge.

Mr. Fowler and I are of opinion, therefore, as a result of our two years' further consideration, that the assumed pressure of 56 lb. per square foot over the whole of the bridge is considerably in excess of anything likely to be realized. It is another question whether the method of estimating the effective area exposed by the bridge, namely, double the plane surface, with a deduction of 50 per cent. in the case of tubes, is right or wrong. We think it is a sufficiently near approximation of the truth, for reasons which I will briefly set forth.

As all engineers well know, one of the results of the panic caused by the fall of the Tay Bridge was the appointment by the Board of Trade of a committee to consider the question of wind pressure on railway structures, which committee advised the adoption of certain rules Shortly stated, these were:

1. That a maximum wind pressure of 56 lb. per square foot should be provided for.

2. That the effective surface upon which the wind takes effect should be assumed at from once to twice the front surface, according to the extent of the openings in the lattice girders.

3. That a factor of safety of four for the ironwork, and of two for the whole bridge overturning as a mass when gravity alone comes in, should be adopted. In the case of the Forth Bridge we took, with the approval of the Board of Trade, the highest ratio for the surface, namely, twice; but I must admit that I had not the slightest idea at the time whether the twice ought not to be thrice and even more, and the recommendations of the committee did not assist me, as they were founded on no special experiments, and did not accord with my own experience so far as it then extended. Under these circumstances the necessity of further experiments was clearly indicated, and we have made them.

The tension members and the bracing of the Forth Bridge, as already explained, are lattice box girders, and the main compression members are tubes. Thus, in the case of the top tension members near the piers, we have the front surface of the girder with channel bars and projecting flanges, making it essentially different to the flat anemometer plate, and three corresponding surfaces, situated respectively about 7 ft., 33 ft., and 40 ft. to the rear of the front surface. In the case of the tubes we have the tube itself, then a couple of box lattice cross braces, with channel bar, members, and finally another tube. No theory exists which could enable us to estimate even approximately the equivalent flat surface of such a network; and I felt, until my scheme of experiment by models was realized by satisfactory results, that our calculation of stresses from wind pressure rested on anything but a logical basis. The problem to be solved was how far the eddies caused by the front surface affected the surfaces to the rear. In the recommendation of the "Wind Committee," a front plate girder was considered to give complete shelter to any girders to the rear of it, but I think any one who has walked "Indian file" in a gale of wind will have noticed that unless he locked up pretty closely to the front man he felt practically the full force of the gale; and similarly unless the rear plate girders of a bridge be relatively close to the front girder, the latter will not afford anything like complete shelter. It is obvious, therefore, that the depth of the girders and the distance apart enter into the problem, as well as the question of their being plate or lattice; and I may add further that the position and character of the floor between the girders also materially affect the wind stresses.

My original idea was to prepare models and test them in actual wind at Inch Garvie, but the irregularity of the results, even with the flat boards, precluded the possibility of any useful data being so obtained. I determined, therefore, to abandon the attempt to measure actual resistances, but to arrive at the same end by getting the equivalent area in flat surface of the different bridge members and cross bracing, and for this purpose devised a very simple pendulum arrangement, consisting in effect of a crossbar with a model at one end and an adjustable flat surface at the other of exactly equal weight, which bar was suspended at the center, so that the only resistance to turning was the torsion of the suspending string. On oscillating this pendulum, if the flat surface were not the exact equivalent in resistance of the model, one or the other would advance, and the sensitiveness was such that different observers would rarely vary more than 3 or 4 per cent. in their results.

To test the sufficiency of this simple apparatus, I contrasted the resistances of thin flat surfaces and cubes, and my results agreed within 2 or 3 per cent. of those obtained in the most elaborate manner by Dubuat many years ago. Similarly, the results obtained with cylindrical surfaces and inclined planes were in strict accord with those obtained by previous observers and other apparatus. When experimenting with sheltered surfaces, however, my results differed considerably from previous experimental ones, which I must say are singularly few in number, having reference to the vast importance of the subject to engineers. Thus, according to Thibault, the resistance of the rear plate of a pair set at a distance apart equal to the diameter is 0·7 of that of the front plate, while in my experiments I found no such excess until the distance apart was 3½ diameters. I experimented with disks placed at from 1 diameter to 4 diameters apart, and the resistance of the two disks in terms of that of the single one was in round numbers 1·0 for 1 diameter, 1·25 for 1½ diameters, 1·4 for 2 diameters, 1·6 for 3 diameters, and 1·8 for 4 diameters. An increased number of disks placed intermediately between the front and rear disks little affected the resistance. For example, by reducing the 4 diameters to 3·6 diameters, an extra disk could be introduced without increasing the resistance of 1·8, and by still further reducing the distance to 3·5 diameters 4 disks could be employed. This result is of great importance in its bearing on railway bridges where a succession of lattice bars may occur one behind the other, which would offer a very large surface to the wind if the proper way of estimating that surface were to take a slightly angular view of the bridge and measure up all that was visible.

It has already been mentioned that in the "Wind Committee's" report no addition is made for sheltered surfaces in the case of plate girders, while it might appear from the foregoing experiments that as much as 80 per cent. allowance should be made where the girders are four depths apart. This would, however, be a very fallacious deduction, for it omits all consideration of the floor of the bridge. Reasoning from the observed resistance of cubes, it may be inferred that the resistance of a tubular girder, such as the Britannia Bridge, would be only 80 per cent. of that of a single flat girder, and clearly the floor of a girder bridge, if close plated, makes the conditions approximate to that of the tube. As a matter of fact, I found that two plates connected by a floor plate at the bottom offered no more than 90 per cent. of the resistance of the single plate. Summarizing my conclusions, for it is impossible to give details here, I should say that the effective surface of a plate girder bridge would range from 90 per cent. to 180 per cent. of that of the front surface, according to the distance apart of the girders, the degree of openness of the floor, and its position relative to the main girders.

In many respects the preceding remarks apply to lattice girders, but the varying extent of the open spaces between the bars introduces an additional complication. When the openings were one-fourth of the whole area, I found for a distance of one diameter apart an increased resistance of 8 per cent. from the second disk, while with openings of double the size the increase was 30 per cent. At two diameters the respective amounts were 40 per cent. and 66 per cent., while at four diameters the more open lattice reached 94 per cent. In other experiments, sometimes with a small flat plate in front of a lattice, and sometimes in the rear, I obtained at four diameters distance resistance exactly equal to the sum of the two specimens tested separately.

The top member of the Forth Bridge consists, as I have said, of a pair of box lattice girders or, as may be said equally truly, of four single-web lattice girders. Models of these single-web girders, tested in pairs, gave 20 per cent. increase from the rear girder when the distance apart was equal to the depth, 50 per cent. for two depths, 70 per cent. for three depths, and 80 per cent. for four depths. When three girders were placed one behind the other, the middle girder gave rise to a further increase of about 4 per cent. for three depths and for four depths; in short, it mattered practically little whether two, three, or four girders were used. Two models of a complete bay of the top member were made, one as light as possible, and the other somewhat heavy. The results were in accord, the resistance averaging 1·75 times that of the plane surface, while that of each of the lattice box girders tested separately was 1·15. As a factor of 2 instead of 1·75 was used in the wind calculations, the pressure on the lattice members has been somewhat overestimated, but, on the other hand, that on some of the other members of the bridge, judging from the results of the experiments, has been somewhat underrated.

The bottom member and the main struts of the bridge consist of a pair of tubes braced together by box lattice girders. I tested a complete bay of the bottom member, and found the resistance of the two tubes, placed seven diameters apart, together with the two box lattice braces, of a depth equal to the diameter of the tubes, to be 1·1 times that of the plane surface. Substituting plate girders for the lattice braces, the ratio was still only 1·24, so the tube evidently acted as a sort of cut-water, and by clearing a path for the flat surfaces lessened their resistance. This was further proved by removing one of the tubes, and testing the single tube and cross lattice bracing. Tube in front the resistance was but 80 per cent. of that obtained when the lattice was to the fore. The lattice bracing tested alone had a resistance equal to 60 per cent., while, when in position between the two tubes, it only increased the resistance about 5 per cent. This, perhaps, was to me the most reassuring of all the experiments, because, looking at a complete model of the bridge, it appeared as if the intricate mass of cross-bracing must offer an enormous resistance to the wind. As a matter of fact, so far as my experiments extend, it would seem that the eddies caused by the front surface extend to a great distance in all directions, and in a complex structure the innumerable and conflicting eddies would almost appear to neutralize each other as regards some of the sheltered surfaces. On the other hand, in simple isolated structures, such as a pair of bars or tubes, the shelter is practically *nil* at distances equal to about six diameters, and the members might as well be abreast. This was well demonstrated in the experiments by arranging the models on the skew so as to imitate the effect of a wind blowing at an angle to the horizon, when constant results were obtained with widely different angles.

In the approach viaduct at the Forth the lattice girders are under the rails, and there is a wind fence on each side. Testing a model of this class of construction, I found that the resistance of the parapet and of the railway carriages was only two-thirds of the corresponding plane surface, a result due no doubt to the eddies thrown up by the girders. It would appear therefore that current estimates of the wind pressure required to overturn railway carriages on exposed viaducts should be further considered, for although an average carriage might overturn with a uniform pressure of 40 lb. per square foot, a 60 lb. wind may be necessary to produce the equivalent of that pressure. In our model of a pair of lattice girders with floor, wind fence, and railway carriage on the top, the total resistance was but 93 per cent. of that due to the plane surface. As by the present rules engineers would in such a case estimate the equivalent at about 150 per cent., it follows that in many recent and presumably

future bridges the actual wind stresses may be considerably less than estimated.

The leading constituent parts of the Forth bridge were tested, as described, by models of single members and of complete bays, but we proceeded a step further and tested both in air and in water a complete metallic model of two pairs of cantilevers with cross bracing, internal viaduct, and wind fence, together with the intermediate part over the Inch Garvie piers. The total resistance so ascertained was 9 per cent. greater than that obtained by calculation on the basis of taking double the plane surface with a deduction of 50 per cent. in respect of tubes. With the models of different parts tested separately, the excess was 4 per cent. This excess would not apply to the moment of the wind pressure, because the highest parts of the bridge are lattice structures, the resistance of which was overestimated. If 56 lb. wind ever occurred as a mean over such an area as that we are dealing with, it would be something greater at the high level of the lattice top member and something less at the level of the bottom tubes.

Personally, therefore, I am satisfied that the asumption originally made by ourselves and the Board of Trade officers was a sufficiently close approximation to the truth for all practical purposes. I do not attach undue importance to the results obtained by the models nor to the records of our large and small pressure boards at the Forth, but at the same time to me they have thrown a little daylight on many obscure questions respecting the actual wind pressure in railway bridges and other structures. Mr. Stewart and I would sometimes attempt to calculate the resistance of a model upon hypotheses of our own, and differ most widely in our results, as others who have attempted the same thing have generally done. A single swing of the long pendulum would solve all our doubts and difficulties. In arranging the experiments, I had regard to Froude's principles as to velocity relative to the scale of the models, and believe the eddies and interferences to be similar in kind in the models and bridge. Of course what is wanted is the measured resistance of actual bridges in actual storms, but this I have not yet been able to undertake.

Such experiments as I have been able to make have at least served to show how little is known about wind stresses, and how necessary it is that every engineer should seize such opportunities as may offer for contributing something to the general store of information.

Two years ago I said I should have preferred to have postponed any communication on the subject of the Forth bridge to the British Association "until the many points of interest and difficulties inseparable from so gigantic an undertaking had manifested themselves." I am in much the same position now, for it will be gathered from the present paper that no real strain has yet been put upon the resources of the contractors or the capacities of the executive officers. Two years hence I may, perhaps, have a more thrilling tale to tell. Much interest in the work has been evidenced by Continental and American engineers, and the criticism on the whole, has not been unfavorable, but appreciative. Occasionally it has been suggested that the appearance will not be as elegant as could be desired, but I retort, mentally, in Lord Bacon's words, "Houses are built to live in, and not to look on; therefore let use be preferred before uniformity, except where both may be had." We aim at getting both, and our granite faced piers, their simple but bold mouldings, certainly look better than cluster-columned metallic piers, however scientific. Thus far we have succeeded in satisfying our masters, and very keen critics, the directors of the North-Eastern, the Midland, the Great Northern, and North British Railways, and the officers of the Board of Trade, both as regards the quality and appearance of the executed work.

If I were to pretend that the designing and building of the Forth bridge was not a source of present and future anxiety to all concerned, no engineer of experience would believe me. Necessarily, where no precedent exists, the successful engineer is he who makes the fewest mistakes. We cannot wait for precedents, and therefore as successive points of doubt or difficulty arise, we reason them out on the best data attainable, and then in the land of Burns' we act up to Burns' favorite motto,

"On reason build resolve—
That column of true majesty in man!"

[Continued from SUPPLEMENT, No. 502, page 8014.]

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ON THE CONVERSION OF HEAT INTO USEFUL WORK.*

By WILLIAM ANDERSON, M.Inst.C.E.

LECTURE VI.

I HAVE now reached the stage of my lectures when it becomes necessary to consider heat-engines proper, that is to say, mechanical contrivances more or less complicated, whereby the heat imparted to the agent is converted into work; but before I begin, I must introduce you to a little instrument called the indicator, which is used for the purpose of depicting automatically the changes of volume and pressure which take place in the agent when a heat-engine is working. Nearly all heat-engines are actuated by heated expansive gases pressing upon pistons working in closed cylinders or spheres, and the amount of work which is performed is proportional to the volumes described by the pistons, multiplied by the mean pressure exerted against them. The indicator is merely a small working cylinder which can be placed in communication with that of the engine. The cylinder has usually an area of half a square inch, and is fitted with a piston, to the rod of which is attached a pencil, arranged so as to trace a line on the paper-covered roll, which is made to rotate with a reciprocating motion at a speed proportional throughout to that of the piston of the engine. The indicator piston is held down by a spring, the elasticity of which is accurately known. When there is no communication between the two cylinders, and while the paper-roll is turning backward and forward isochronously with the piston of the engine, if the pencil be applied, a straight line will be traced; this line will represent the atmospheric pressure, or one atmosphere. As soon the connecting cock between the cylinders is opened, the indicator piston, with its rod and pencil, commences at once to follow the movements of the larger piston, the range of motion depending on the pressure inside the large cylinder, the indicator spring yielding till its elasticity is balanced by the pressure of the agent. The pencil, if now applied to the paper, will trace a closed curve which represents, in the direction of the atmospheric line, the distance passed over by the main piston, and, in the ordinates at right angles to the line, the pressures above or below the atmosphere. The area of the figure represents the work done, if the length of it along the atmospheric line be considered to represent the volume of the cylinder.

The indicator diagram, therefore, is a figure which represents, with tolerable exactness, the changes of volume and pressure which take place in the working substance throughout a complete cycle.

THE GAS-ENGINE. (FIG. 37.)

In the case of the explosion of gunpowder in firearms, the working of the machine is intermittent. In repeating guns, indeed, an approach is made to con-

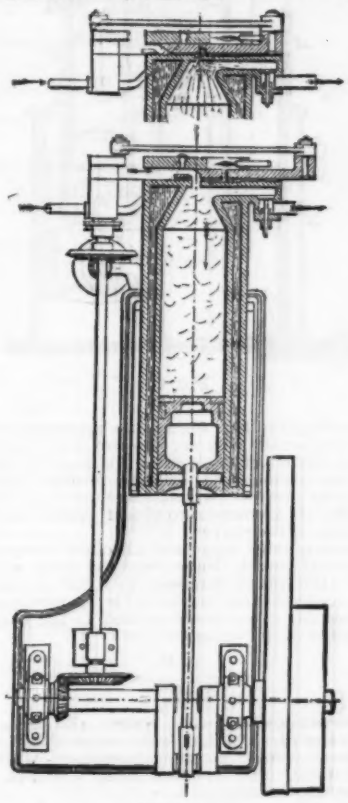


FIG. 37.

tinuous working, though not in an automatic manner, but in gas-engines the force of explosion is made to imitate closely the action of a steam-engine.

The most successful of these motors is that known as the "Otto Silent Engine." I will, therefore, adopt it as a type of this class of apparatus designed for the conversion of heat into useful work. The engine consists of a cylinder fitted with a piston, the rod of which actuates a connecting rod, and by its agency a crank shaft, on which is keyed a fly-wheel, the whole arrangement resembling very much that of an ordinary horizontal engine.

The cylinder is longer than the stroke of the piston, so that at the rear end there is a space or chamber, having a volume of about 61 per cent. of the displacement of the piston. The other end of the cylinder is open to the atmosphere, and therefore the engine is single-acting—that is, the pressure of the working agent comes only on one side of the piston.

Not only is the engine single-acting, but the piston receives an impulse only once in every two revolutions of the fly-wheel, or once in four strokes. During the stroke in which the impulse is given—which lasts one-fourth of the complete cycle—the pressure accelerates the motion of the fly-wheel and other moving parts, and the energy so accumulated is given out during the remaining three-fourths of the cycle. The velocity of rotation necessarily varies in a proportional degree. For the purpose of keeping the cylinder cool, it is surrounded by a jacket, through which a stream of water continually circulates.

A complete cycle consists of the following operations:

1. The piston makes a forward stroke, and draws in a supply of gas and air through a slide valve in the rear of the cylinder. At the end of the stroke, the slide valve closes the passages; and

2. The piston makes a return stroke, and compresses the air and gas into the chamber at the rear end of the piston.

3. The explosive mixture of gas, air, and the residue of the products of combustion of the previous stroke is ignited, very rapid combustion, rather than explosion, takes place, and is barely completed before the piston attains the end of its second forward stroke. The heated gases expand, giving out work, and accelerate the motion of the moving parts. When the end of the stroke is nearly reached, the exhaust valve is opened, and

4. The piston in its second return stroke partially drives out the production, and restores everything to the same condition as it was at the beginning of the cycle.

Pursuing the plan I have adopted in these lectures, I will discuss this prime mover in connection with an actual example, viz., that of a ten-horse engine experimented on by Messrs. Brooks and Steward, at the Stevens Institute of Technology, in New York, in the year 1883.

This engine had a cylinder 8½ in. diameter by 14 in. stroke. I will select experiment No. 19, made when working full power. An indicator diagram (Fig. 38) was taken, and it sets before you all the changes which took place during one of the cycles. Let us consider the four strokes in detail.

1. The first outward stroke.—The indicator diagram shows that a vacuum, amounting to 0·15 of an atmosphere, or 2·2 lb. per square inch, was produced in drawing in the air and gas, the exact quantity of which, consumed during the 30 minutes run, was measured by accurate meters and found to be 3·76 lb. of gas and 60·38 lb. of air, being in the proportion of 1 : 16. The gas used was of inferior quality, and required only 12½ lb. of air per 1 lb. of gas for perfect combustion, so that the quantity actually used was 28 per cent. in excess. With good gas, such as is generally supplied to London, you will see, from the table of "Properties of Fuels," that 15·66 lb. of air are required for a pound of gas.

2. In the return stroke, the air and gases were rapidly compressed into a little more than one-third of their

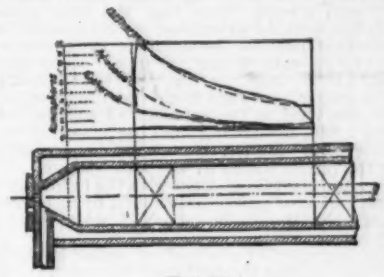


FIG. 38.

volume. The engine made 160 revolutions per minute, so that the compression must have taken place in a little over one-fifth of a second, consequently we should have expected the pressure of the gases to rise nearly according to the ordinates of an adiabatic curve, such as I have traced in dotted lines on the indicator diagram. The water-jacket, however, carried off the heat due to the energy expended in compression so fast that the curve barely rose above the isothermal, which I have also indicated by a dotted line. The work, which was negative, that is, performed upon the agent, had been done at the expense of the energy latent in the fly-wheel, and had it been possible to prevent the escape of heat, no permanent loss would have been sustained, because the same amount of work would have been given out on the return stroke; but under the actual circumstances, energy, represented by the difference between the work done along the two curves, has been carried off by the water-jacket, and lost, so far as the engine is concerned.

3. At the turn of the stroke, the explosive mixture is fired by an ingenious arrangement in the slide valve, by means of which a pinch of gas—if I may use the term—is set alight by a jet constantly burning behind the valve, and carried, before combustion ceases, into the passage communicating with the cylinder through which the contents of the latter are ignited.

As you see by the vertical line on the left of the diagram, which represents the rise of pressure due to the explosion, the combustion is very rapid, and its intensity reaches a maximum before half an inch of the stroke is accomplished, or in about one-fiftieth part of a second, the pressure rising from three atmospheres absolute to ten, and then sinking as the volume of the gases increases. The fall of pressure ought to be according to the ordinates of an adiabatic curve; but in reality, as you see by the dotted line which I have introduced into the diagram, the curve rises a little even above an isothermal.

When within about 1½ inches of the end of the stroke, the exhaust valve begins to open, and, 4th, in the return stroke, the products of combustion are expelled at a temperature of 790°, or 1,250° absolute.

The gas used in this case, I have already said, was of poor quality. Mr. Deering has been good enough to calculate its thermodynamic value for me, and he finds that, supposing it to have been saturated with vapor of water, the combustion of 1 lb. would yield 17,096 units of heat.

During the half-hour over which the observation extended, 3·764 lb. of gas were used, the total weight of complete fuel and products was 84·711 lb., and 20·568 lb. of products of combustion at 1,250° absolute remained in the cylinder, consequently the mixture of gas, air, and products, taking due account of the variations of specific heat, must have had a mean temperature of 734° absolute. The indicator diagram shows that the temperature did not change sensibly during the compression of the mixture, hence the total heat of combination was $17,096^{a} + (734^{\circ} \times 0{\cdot}188) = 17,234^{a}$ per pound of gas, reckoning from absolute zero. The mean specific heat of the gases must here be taken as that due to constant volume, and proves on calculation to be 0·188. The absolute temperature should rise to

$$\frac{3{\cdot}764 \text{ lb.} \times 17,096^{a}}{84{\cdot}711 \text{ lb.} \times 0{\cdot}188} + 734^{\circ} = 4,781^{\circ},$$

if chemical reaction were complete, but this temperature is higher than that at which dissociation takes place, so that it could not possibly be reached.

We can approximate to the true temperature, however, by calculating from the pressures which the indicator diagram declares. The temperature of the mixture of gases before explosion was 734° absolute, at 3 atmospheres pressure; this rose at once to 10 atmospheres, hence the temperature, allowing for the contraction of volume which takes place in the chemical reaction, and for the increase of volume due to the piston having moved forward half an inch, must have been $\frac{734^{\circ} \times 10\ at \times 5{\cdot}82v}{2{\cdot}904\ at \times 5{\cdot}32v} = 2,712^{\circ}$ absolute. This point is not capable of exact determination by calculation, because of the uncertainty as to the specific heats of substances at high temperatures. The true value must be somewhat higher than the figures arrived at, because the indicator, owing to its own friction and

* Lectures recently delivered before the Society of Arts, London.

inertia, is sure to register the pressures lower than they really are, especially when the action is so rapid as it is in the case of gas-engines. I think it will be safe to assume that the maximum temperature attained was about 3,000° absolute. Under such circumstances, the duty to be expected, according to Carnot's doctrine, would be $= \frac{3{,}000° - 1{,}350°}{3{,}000°} = 0{\cdot}583$, and the total available power for which the engine might fairly be made debtor would be

$$\frac{3{\cdot}764 \text{ lb.} \times 17{,}234^{ft} \times 772^{ft} \times 0{\cdot}583}{30' \times 33{,}000} = 29{\cdot}49 \text{ horse-power.}$$

The circumstance that the expansion curve of the indicator diagram follows the isothermal, and not the adiabatic, and the lowness of the temperature when the maximum pressure is reached, show that the combustion must continue for at least the whole stroke, and probably even some way along the return. It is only by such a supposition that the heat communicated to the working substance, as it expands, can be accounted for, because the metal of the cylinder, surrounded by its water-jacket, is much cooler than the gases, and, so far from heating, must tend to cool them. Again, working backward from the final temperature of 1,250°, the heat, at the moment of exhaust, should be about 1,800°, calculating from the pressures, whereas it is quite 1,000° higher, the excess being carried off during the return stroke by the water-jacket.

The engine must be credited with the following work:

1. The indicated power ascertained by measuring the diagram, being the useful external work done = 8½ horse-power.

2. Heating up 9·75 cubic feet of water in the jacket 43·38° Fahr., during the half-hour for which the experiment lasted, this represents—

$$\frac{9{\cdot}75 \text{ c.ft.} \times 62{\cdot}2 \text{ lb.} \times 43{\cdot}38° \times 772^{ft}}{30' \times 33{,}000} = 20{\cdot}52 \text{ horse-power.}$$

Third, and finally, a certain amount of loss by radiation, convection, and leakage, amounting to 0·47 horse-power.

Dr. BALANCE-SHEET OF GAS-ENGINE. *Cr.*

	Horse-power.		Horse-power.	Per cent.
Available power..	29·49	Indicated power.....	8·5	28·83
		Carried off by water-jacket.....	20·52	69·58
		Loss by radiation, etc.	0·47	1·59
	29·49		29·49	100·00

The water-jacket, which is an unfortunate mechanical necessity in consequence of there being, at present, no other known method of keeping the working parts in a state of efficiency at high temperatures, consumes, as you see, nearly 2½ times as much heat as the useful work given out. The practical efficiency of this particular engine was only 8·½ horse-power out of a total of 50·53 possible if the products could have been cooled to absolute zero; this realized, therefore, only 17 per cent. of the energy latent in the gas.

With good gas, it is said that the engines consume only 21 cubic feet per indicated horse-power per hour; a reference to the table of "Properties of Fuels" tells us that 1,000 cubic feet of good gas will yield 617,485 units of heat, hence 21 cubic feet per hour would yield per minute—

$$\frac{617{,}485^{ft} \times 21 \text{ c. ft.} \times 772^{ft}}{1{,}000 \text{ c. ft.} \times 60' \times 33{,}000} = 5{\cdot}056 \text{ horse-power, capable}$$

of producing only 1 horse-power, so that even good gas will only yield a duty of 20 per cent. Carnot's theory enables us to give a reason for this result. First, the initial temperature cannot be raised to the highest point possible; and, secondly, the terminal temperature is excessively high. In addition, there is the terrible waste in the water-jackets. The theory we have been considering indicates that a higher range of duty is attainable, and I am sure that the time will come when, by suitable mechanical contrivances, better results will be obtained. One method of improving the economy, though not the efficiency, of gas-engines is to use crude gas, generated in a producer somewhat on Siemens' system. By this means, nearly the whole of the coal is converted into various gases, and is used at once in the engine. The table of the properties of fuels tells us that Wigan coal, for example, produces 14,051 units of heat per 1 lb. of coal. If consumed in an hour this would yield $= \frac{14{,}052^{ft} \times 772^{ft}}{60' \times 33{,}000} = 5{\cdot}48$ horse-power, and at 20 per cent. duty should give 1·1 horse-power. As a matter of fact, 1 lb. of coal applied in this way, on a large scale, is yielding seven-tenths of a horse-power. With all its imperfections, however, the gas-engine has taken a firm place as a trustworthy, safe, convenient, and even economical contrivance for the conversion of heat into useful work.

HOT-AIR ENGINE. (FIG. 39.)

We now come to the investigation of the properties of an agent in the conversion of heat into work, respecting which an immense amount of inventive genius has been employed. I allude to hot air.

Air, being a mixture of gases which do not alter their physical properties through a wide range of temperature and pressures, is peculiarly fitted for illustrating the theoretical aspects of the subject before us. The specific heat of air, at constant volume, when the increase of its temperature is unaccompanied by the performance of external work, is 0·169. The pressure of a given volume of air, when heated, increases as its absolute temperature, if there is no change of volume, and, at first sight, it would appear that if air were heated in a confined space and then allowed to expand, doing external work, the whole of the heat imparted could be converted into work, and the air rejected at the normal temperature and pressure of the atmosphere. If this could be done, a perfect engine would be the result; but the fall of temperature in air, when used as a working agent, does not keep pace with the fall of pressure.

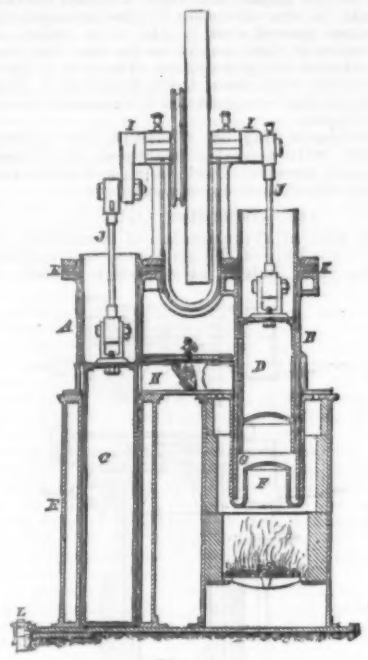


FIG. 39

On the diagram (Fig. 40), I have represented the relations between the volume, pressure, and temperature of say ten cubic feet of air at 40° Fahr. or 500° absolute, and at one atmosphere absolute pressure, that is, at the ordinary pressure which surrounds us. The base line represents absolute zero of temperature, and forms the abscissa of the curves.

The vertical lines represent absolute temperatures. The diagonal line, A, drawn from the point where 500° and one atmosphere intersect to 5,000° at ten atmospheres, represents the increase of temperature required to produce any given pressure, and is the graphic representation of the equation—

$$T_1 = \frac{T\,P_1}{P}$$

The curved dotted line, B, defines the temperatures to which the air will fall when expanding from any given pressure down to one atmosphere while doing external work. The equation from which these temperatures are calculated is—

$$T_1 = \frac{T}{\left(\frac{P}{P_1}\right)^{0{\cdot}29}}$$

If these calculations are correct, then the work done in expanding must correspond with the energy latent in the number of units of heat which have disappeared.

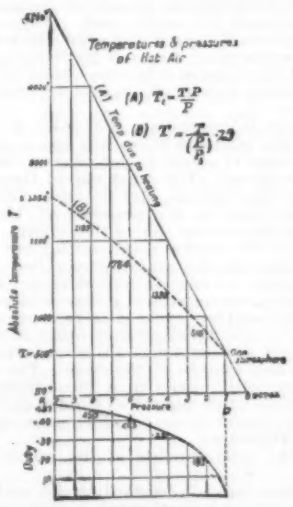


FIG. 40.

Take the case where, by heating the air to 2,000°, a pressure of four atmospheres is attained. On expanding and doing work, the temperature will fall 662°, or down to 1,338° absolute. The weight of ten cubic feet of air at 500° and one atmosphere is 0·7944 lb.; hence the energy which has been changed into motion is = 662° × 0·7944 lb. × 0·169 × 772^{ft} = 68,611 foot-pounds.

The work done in expanding along the adiabatic curve is—

$$= \frac{10 \text{ c. ft.} \times 2{,}116{\cdot}8 \text{ lb.} \times 4 \text{ at.}}{0{\cdot}408} \left\{1 - (\tfrac{1}{4})^{0{\cdot}29}\right\} = 68{\cdot}693 \text{ foot lb.}$$

The value 2,116·8 lb. is the pressure of one atmosphere in pounds per square foot. The two results are practically identical, and hence, because the energy in the air is proportional to its temperature, the triangle bounded by the diagonal line, A, will represent the total potential energy of the air at various temperatures and pressures, while the curve, B, shows how much is capable of being rendered kinetic; the ratio, in any ordinate, of the piece between the dotted and the full lines to its total length represents the proportion of heat which can be utilized, and is in effect Carnot's function—

$$\frac{T - t}{T}$$

The curve beneath the upper figure indicates how rapidly the possible duty diminishes with the decrease of temperature. At four atmospheres the duty can only be 33 per cent., yet under these disadvantageous circumstances a horse-power could, theoretically, be produced for a little more than half a pound of coke per hour.

Referring to the fuel table, you see that coke yields 13,640 units of heat. By suitable arrangements it can be used to heat air so that the waste products shall escape at about 800° absolute; taking 4,000° as the maximum temperature of the fire, we may expect to realize $\frac{4{,}000 - 800°}{4{,}000°} = 0{\cdot}80$, and, therefore, counting from absolute zero, the available heat will be—(13,640 + 82) × 0·8 = 10,978 units.

The air has been heated from 500° to 2,000°, absorbing 1,500° × 0·7944 lb. × 0·169 = 201·4 units at the expense of $\frac{201{\cdot}4}{10{,}978} = 0{\cdot}0184$ lb. of coke. If the work done by this heat be performed in one minute, it would indicate $\frac{68{,}693 \text{ foot-pounds}}{33{,}000 \text{ foot-pounds}} = 2{\cdot}08$ horse-power. The coke consumed per hour would be 0·0184 × 60 = 1,104 lb., and, therefore, the coke consumed per horse-power per hour would be $\frac{1{\cdot}104 \text{ lb.}}{2{\cdot}08 \text{ h.p.}} = 0{\cdot}53$ lb.

Again, in this particular case, out of the total 2,000°, only 662° have been utilized; there remains 838° available before the exhausted air sinks in temperature to that of the surrounding atmosphere. Can no use be made of this heat? An answer was given to this question by Stirling, at the beginning of this century, when he invented the regenerator, which has since become widely known in connection with other heat appliances. In hot-air engines the regenerator consists of a number of metal plates, tubes, or sheets of gauze, through which the air passes to and fro; the hot air, in passing through, heats the metal, and the cold air, in returning, is, in its turn, heated by the hot plates, the zone of heat oscillating backward and forward with the air.

One of the most successful of the hot-air engines is known as the Rider engine; it is manufactured by Messrs. Hayward, Tyler, and Co., to whom I am indebted for the diagram (Fig. 39) on the wall and for this working model. The engine consists of two plungers, C and D, coupled by means of connecting rods to cranks keyed at right angles to each other on a crank shaft common to both; one plunger, D, called the power plunger, works in a cylinder kept permanently hot by means of a fire, while the other, C, called the compression plunger, works in a cylinder surrounded by a water-jacket. The two cylinders are connected by a wide passage, H, fitted with plates, and constituting the regenerator. There is no change of air in this engine, but the relative motions of the two plungers cause a constant variation in volume and interchange of air between the two cylinders; the increasing volume on the forward stroke synchronizes with an increase of the heating power, because most of the air is in the hot cylinder, while the decreasing volume in the "in" stroke is provided for by the preponderance of cooling power, because most of the air is in the cold, water-jacketed cylinder. The power plunger, D, has the lead of the compression plunger by a quarter of a revolution. Suppose it to have completed half its upward stroke, as on the diagram, the compression plunger being right down; most of the air, considerably compressed, is on the hot side, and is being rapidly heated and expanded. The consequent pressure impels the power plunger, D, outward, and, being transmitted through the regenerator, H, acts on the compression plunger, C, whose crank has just turned its bottom center; both plungers now move upward and drive the crank shaft. By the time the power plunger, D, has reached the top of its stroke, a considerable volume of air has passed through the regenerator, been cooled by it, and filled half the compression cylinder, C, where its temperature is further lowered by the water-jacket, E. The momentum of the fly-wheel, aided by the pressure in the compression cylinder, C, now carries the power plunger down against the pressure, but by so doing reduces the volume of air exposed to the fire, and increases that subjected to the cooling influence, so that the balance is against the fire.

By the time the power plunger, D, has descended half its stroke, the compression plunger also begins to descend, and to compress the cold air under it, and drive it backward through the regenerator, H, from which it takes up the heat into the power cylinder, D, where it gets further warmed, till the power plunger again begins to ascend, and attains the half stroke, so completing the cycle. The supply of air, to make up for leakage, is derived from a small inlet pipe, I, attached to the bottom of the compression cylinder, and fitted with an automatic valve opening inward. At the turn of the stroke, if there is any deficiency of air, a partial vacuum is formed, which causes a fresh supply to rush in. There are no distributing valves in this engine, and each plunger works through a leather-packed gland, K, which, in the case of the power plunger, is kept cool by a water-collar immediately under it.

The power cylinder is surrounded, for about half its lower length, by an iron jacket, F, around which the fire plays, the air passes backward and forward through the annular space between the cylinder and the jacket, and by that means is not only heated itself, but prevents an excess of heat reaching the cylinder. The regenerator is filled with cast-iron plates about ⅛ inch thick, placed ⅛ inch apart. The speed varies from 100 to 140 revolutions per minute. I have been unable to obtain any satisfactory data as to temperature, except that the air is heated to the dull-red heat of cast iron, which may be taken at 1,000 Fahr. The water-jacket,

as in the gas-engine, carries off a good deal of heat, which is, therefore, incapable of being converted into useful work. There are a great variety of air-engines, and though extremely useful for small powers, the whole class is not of sufficient importance to claim more of our attention.

COMPRESSED AIR REFRIGERATING MACHINES. (FIGS. 41, 42.)

In the compressed air refrigerating machines we have an interesting example, first, of the conversion of heat into work through the agency of steam; next, the development of heat by the energy so obtained being employed to compress air; and, finally, the absorption of heat by the compressed air being made to do work in its turn. Through the kindness of Mr. Hesketh, the senior representative of the old house of J. & E. Hall, of Dartford, I am enabled to exhibit the drawings of one of their refrigerating engines, to which three gold medals were awarded at the Health Exhibition.

FIG 41.

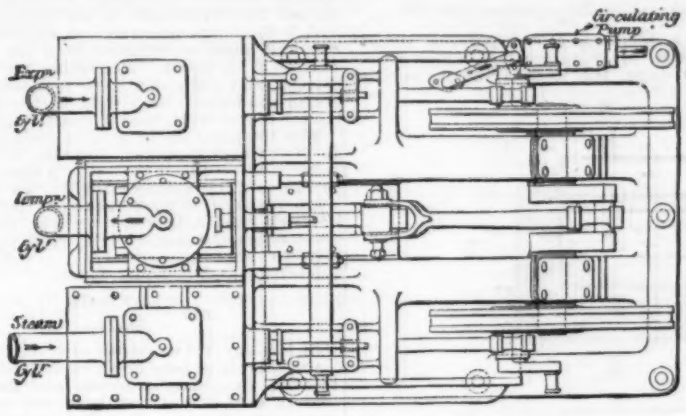
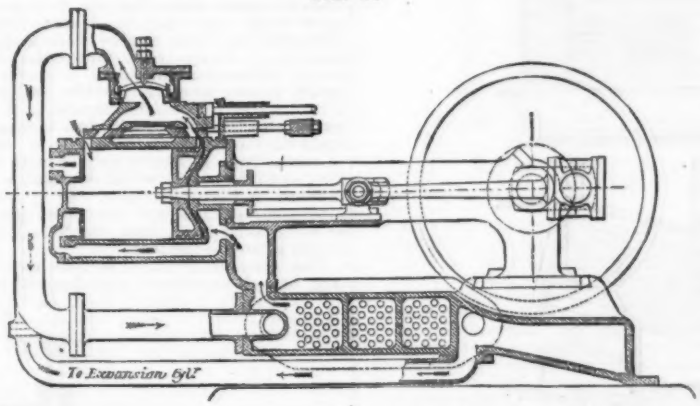
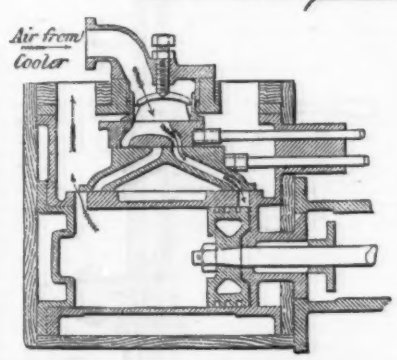


FIG. 42.





The machine consists of three cylinders, fitted with metallic pistons placed side by side, and connected by a crank shaft, common to all, by means of piston rods, crossheads with slipper guides, and connecting rods, in the manner common with ordinary horizontal engines. The same crank shaft drives a water circulating pump, and beneath the frame which carries the whole mechanism is a tubular refrigerator. The lower cylinder in the diagram is of the kind ordinarily made for steam engines, and may be constructed with expansion valves, steam jacket, and all other accessories suitable for a steam engine of the best construction. The power developed in this cylinder is transmitted through to the crank shaft, by an overhung crank, to an intermediate crank, which actuates the piston of the middle or air compressing cylinder, which is water-jacketed, and fitted with double slide valves, of peculiar construction and proportions, through which air is drawn in from the outside atmosphere and delivered, compressed to about 45 pounds per square inch, and at a temperature of about 250°, to the tubular refrigerator. The hot air circulates through a number of metal tubes, round the outsides of which passes a current of water supplied by the circulating pump, actuated by the upper end of the crank shaft. The water rises about 10° in temperature, and carries off, in the form of heat, a portion of the energy of the steam engine. The compressed air, reduced to nearly the normal temperature, and at a pressure of 45 lb. per square inch, next enters the upper cylinder on the diagram, through double slide valves, also of special construction, and is made to expand, doing work upon the piston, and therefore its temperature falls in proportion to the amount of energy communicated to the crank shaft, which energy is applied to reduce the work to be done by the steam. The temperature of the air is reduced by this means to as much as 130° below the freezing point. In some cases, instead of drawing air into the compression cylinder from the atmosphere, it is drawn from the refrigerated chambers, and is made to pass over a number of tubes containing the compressed air, which is thus cooled to a still lower temperature than was effected by the cooling water, the result being that a relatively lower temperature is obtained after expansion. Simple as the process appears to be, yet, to obtain the best results, great nicety is required in the proportions of the cylinders, in the extent to which the air is compressed, the degree to which the air is expanded, and in the practical details of the valve gear, which are especially important with respect to the difficulties attendant upon the formation of snow and ice derived from the freezing of the moisture always contained in the air. It is the successful treatment of these details which makes the difference between an economical and trustworthy machine and a wasteful or uncertain one. When applied to refrigerate the holds of vessels engaged in the dead-meat trade, the money value depending on the efficiency and trustworthiness of a machine is very large.

Setting aside friction, the power necessary to drive the circulating pump, and the heat represented by radiation and conduction, the useful work done by the steam is measured by the quantity of heat carried off by the water circulating round the cooling tubes and the compression cylinder. The theoretical amount of cooling is easily determined.

The air under an absolute pressure of four atmospheres, and at a temperature a little above that of the surrounding atmosphere, say at 60°, is expanded along the adiabatic curve to one atmosphere; the absolute temperature at the end of the operation will therefore be—

$$\frac{520°}{\left(\frac{4}{1}\right)^{0·29}} = 348° \text{ absolute,}$$

which is 144° below the freezing point, instead of the 130° attained in practice. The air in expanding absorbs a certain amount of heat from the cylinder, and hence the slight discrepancy.

THE STEAM BOILER. (FIGS. 43, 44, 45, 46, 47, 48.)

The last agent in the conversion of heat into useful work which I have to examine is steam, the most important of all, and at the same time the most difficult to investigate exactly. The peculiarity of steam is, that at ordinary temperatures and pressures it is in the liquid form, and is not capable of being used as a working substance. Hence, the application of it must be considered under two heads—first, the conversion of the liquid into an elastic gas; and secondly, the application of the gas so obtained to produce work by means of heat engines. The two operations, though perfectly distinct, are very often confounded together, and the efficiency of steam engines is mixed up with that of the fuel and the boiler.

Water, from which steam is derived, is a substance endowed with a higher specific heat than any other body, that is to say, it requires more heat to raise its temperature one degree. The British unit of heat, as I have already explained, is defined to be the quantity of heat which will raise one pound of water at the freezing point 1° Fahr. Steam also has a higher specific heat than most gases, being 0·370 at constant volume, and, consequently, the value of y, the ratio of specific heat at constant pressure to that at constant volume, is lower, being 1·3, which means that the heat absorbed in the work of expansion bears a smaller proportion to the total heat required to produce a change of temperature than is the case with air, for example, of which the true specific heat is only 0·169.

The diagram on the wall (Fig. 49) represents, in a graphic manner, the properties of steam for 0 to 500 lb. pressure per square inch. The base line is divided into equal parts, and represents the absolute pressures, that is to say, the pressures reckoned from a perfect vacuum.

The ordinates bounded by the inner curve represent the temperatures corresponding to the pressures, according to a scale on the left side of the figure. You will notice that the temperatures rise rapidly from absolute vacuum to about 50 lb. pressure, after which the rise is much more gradual.

The ordinates defined by the upper curve represent at any given pressure, the total units of heat contained in the steam and the water from which it is derived, the latter taken at the freezing point.

Thus, for example, if we wished to know how many units of heat would have to be communicated to a pound of water, at 50°, to produce steam at 35 lb. above the atmosphere, we find that, corresponding to 50 lb., which is the absolute pressure of the steam, we have a temperature of 281°, and 1,116·6 units of heat, reckoned from 32, therefore deducting (50—32) =18° gives 1,148·6 units, the quantity required.

The apparatus in which water is converted into steam is called a steam boiler or generator, and has now assumed certain well defined forms.

For portable purposes, such as are required on railways, in agricultural and traction engines, the familiar locomotive type (Fig. 47) is invariably adopted. It consists of a rectangular firebox, surrounded by a narrow water space attached to one end of a cylindrical shell, the opposite end of which terminates in a tube plate, which is connected to the firebox by numerous small tubes, the outer ends of which terminate in a smokebox, surmounted by a chimney.

For marine purposes, a cylindrical shell (Figs. 43, 44), of which the diameter and length are nearly the same, is fitted with from one to three furnace flues, terminating in a combustion chamber, which is placed close to the rear end of the boiler. This chamber is carried vertically higher than the flues, and is connected over the flues with the front end by a large number of small tubes, which terminate in a smokebox, which is attached to the front of the boiler and is surmounted by a chimney.

FIG. 43.

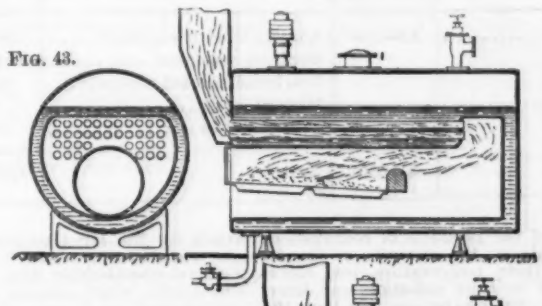
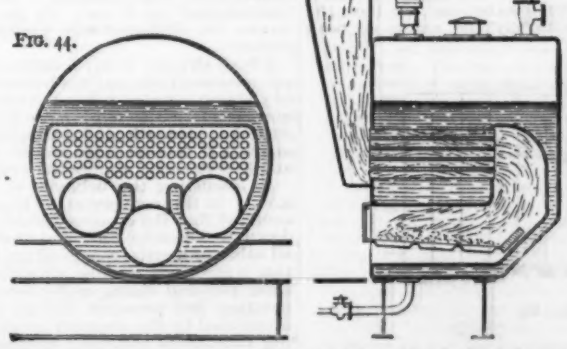


FIG. 44.



For stationary purposes (Figs. 45, 46), the shell is generally cylindrical, the length being much greater than the diameter. Each shell contains one or two cylindrical flues, the front ends of which form the furnaces. The flues are commonly traversed by water pipes, and sometimes terminate in clusters of small tubes. The shells are usually set in brickwork, and the products of combustion are carried round before being consigned to the chimney. For small powers, vertical boilers of innumerable forms are employed, and sectional boilers (Fig. 48), composed of small pipes set in ovens, are not uncommon. Of whatever form a boiler

may be, it is essential for its efficiency that combustion should take place in a furnace of large volume, so that the temperature of the flame may be maintained so long as chemical action is proceeding; and that the proportion between the quantity of heat developed in the furnace and the area of the surface which is destined to absorb the heat should be such that the products of combustion should be finally rejected at as low a temperature as practicable; and that the fall of temperature should be caused by the useful work being done, that is to say, by the heating of the water fed in, and the conversion of that water, when it has reached the proper temperature, into steam. The useless work is the heating of the rejected products of combustion, and the warming of the air and objects around the boiler, by convection and radiation. When these conditions are observed, the application of Carnot's principles shows that there is very little scope for the improvement of steam boilers.

Temperature of Furnace.—The whole of the fuel was heated up, and this, together with the heat absorbed in the evaporation of 26·08 lb. of water in it, lowered the temperature of the fire, and must be deducted from the heat of combustion, leaving thus 2,798,312 units available from 238·25 pounds of combustible = 11,745 units per pound.

$$\text{Temperature} = \frac{11{,}745°}{18{\cdot}125 \text{ lb.} \times 0{\cdot}238} + 530° = 3{,}253°.$$

$$\text{Temperature of products } 700° + 460 = 1{,}160° \text{ absolute.}$$

$$\text{Maximum duty} = \frac{3{,}253° - 1{,}160}{3{,}253°} = 0{\cdot}643.$$

$$\text{Maximum work} = 3{,}248{,}425° \times 0{\cdot}643 = 2{,}101{,}700 .$$

The useful work done was the evaporation of 1,620 lb. of water from 60° at 53 lb. pressure, which represented = 1,855,960 units, the work of displacing the atmosphere by the smoke amounting to 147,720 units, the loss by radiation and convection was ascertained to be 70,430 units, and the heat left in the ashes is estimated at 1,129 units. Arranging these data in the form of a balance-sheet, we see that only 26,521 units of heat are not accounted for.

On the right-hand side of the balance-sheet I have placed a column, indicating the percentage which each of the items bears to the total. You cannot but be

FIG. 45.

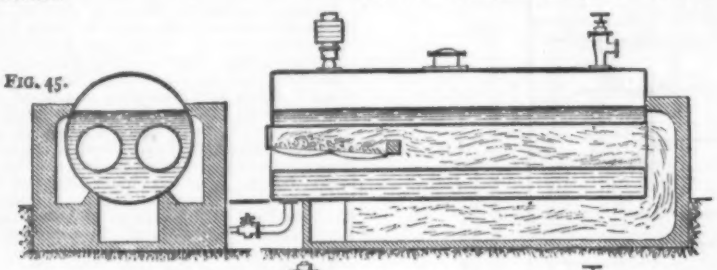


FIG. 46.

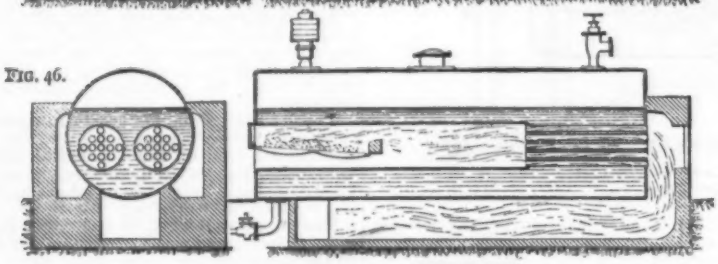


FIG. 47.

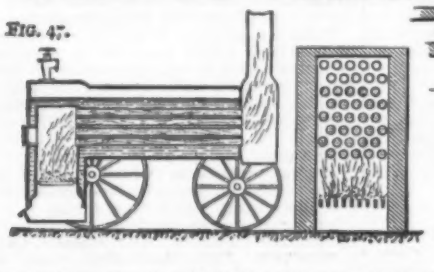
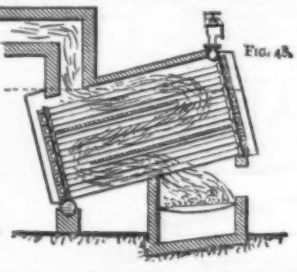


FIG. 48.



BALANCE SHEET OF BOILER.

Dr.	Units.		Units.	*Cr.* Per cent.
Available heat	2,101,700	1,620 lbs. of water evaporated	1,855,900	88·29
		Displacing atmosphere	147,720	7·03
		Loss by radiation and conversion....	70,430	3·35
		Heat left in ash	1,129	·05
		Unaccounted for	26,521	1·26
	2,101,700		2,101,700	100·

both of the fuel and of the products of combustion, was ascertained by analysis; the quantity of air and feed-water used and their temperature was ascertained, and the loss of heat by radiation was determined, so that, in this remarkable case, we have the means of calculating accurately the values on both sides of the account.

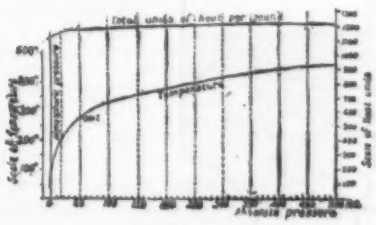


FIG. 49.

The total potential energy of the fuel with reference to absolute zero, the temperature of the air being 70°, was:

	Units.
238·25 lb. fuel × 530° × 0·238	30·053
194·46 lb. carbon × 17¼ lb. air × 530° × 0·238 weight and heat of air.....	420·060
194·46 lb. × 14,544° combustion of carbon	2,828·200
Total energy	3,278·313
Heat absorbed in evaporating 26·08 lb. of water in the fuel.....	29·888
Available energy	3,248·425

struck by the large proportion of energy converted into useful work, as much as 88¼ per cent., and that the next considerable item is the displacement of the atmosphere, which absorbs 7 per cent. The quantity unaccounted for is only 1¼ per cent., which demonstrates the skill and care brought to bear on this experiment.

I have already, in my fourth lecture, dealt with the properties of fuels and the heat which they are capable of yielding. I regret that the time at my disposal will not permit me to enter more fully into the form, construction, strength, and management of boilers. These matters, if treated fully, would in themselves provide ample materials for more than one lecture.

In discussing the behavior of air and other gases as agents in the conversion of heat into work, we have assumed that the gaseous condition would be retained down to absolute zero, and that the specific heat and all other properties remained unchanged. This assumption is incorrect, because all gases, like steam, change their physical states under certain conditions of temperature and pressure, but no sensible error has been occasioned by the assumption made, because the working substances remained unchanged within the range of temperature and pressure under consideration. With steam, however, matters are very different. At moderate ranges of temperature and pressure, steam may be either in the liquid or gaseous condition, so that the work done is not proportional to the fall of temperature.

Take the case of a cubic foot of water converted into steam at 65 lb. absolute pressure, and the corresponding temperature of 298°. Imagine this steam let out of a boiler into the air, the pressure would be reduced to 14·7 lb., the temperature to 212°, and the volume should be increased to 1,642 cubic feet, if it were not for the heat which must be converted into the work of displacing the atmosphere. Could steam expand along the adiabatic curve, the temperature would fall to—

$$\text{Temperature} = \frac{758°}{\left(\frac{65}{14{\cdot}7}\right)^{0{\cdot}23}} = 538{\cdot}5° \text{ absolute,}$$

or to 78° on our ordinary scale, but at that temperature steam would not have the tension due to the pressure of the atmosphere, and would, therefore, be unable to penetrate it.

The cause of the fall of temperature is the work done in displacing the air, therefore there must be an equality between the energy necessary to displace the air and that represented by the units of heat absorbed; and as the temperature cannot fall below 212°, the heat required must be obtained from the liquefaction of a portion of the steam. Neglecting the volume of water formed, and supposing x to represent the volume of steam condensed, then $(1{,}642 \text{ c. ft.} - x) \times 2{,}117$ lb. per square foot = work done in displacing atmosphere.

The temperature of x in condensing falls from 298° to 212°, which from our diagram we find corresponds to 961·8 units of heat per 1 lb. A cube foot of steam at 14·7 lb. and 212° weighs 0·0379 lb., the volume not condensed falls 86° in temperature, so that the foot-pounds of work done represented by the heat liberated by the condensed steam $= (v - x)\, 0{\cdot}0379$ lb. $\times 0{\cdot}305 \times 86° + x \times 0{\cdot}0379 \times 960{\cdot}8 \times 772 = 0{\cdot}994\,(v - x) + 28{,}098x$, these two quantities must be equal, hence,

$$x = \frac{2{,}116 \times 1{,}642}{30{,}214} = 115 \text{ c. ft.;}$$

that is to say, 115 cubic feet of steam will be condensed into water in a very finely divided state, interspersed through the escaping steam, and this water can be plainly seen at the mouth of any pipe discharging steam into the air. But the heat necessary for conversion into the work of displacing the air is not taken from the steam alone, but also from any object it may meet with, hence the hand introduced into a jet of high-pressure steam is not scalded, but when steam issues from the spout of a kettle, the circumstances are totally different; the work of displacing the atmosphere is done when the bubbles of steam are formed in the water, and at the expense of the fire, hence the jet of steam maintains its full temperature, and will scald the hand if introduced into it. After the escape of steam from a pipe, it mingles with the surrounding air, and, if the latter be dry and warm, is quickly diffused as invisible vapor, but if cold, and already saturated, is condensed into small globules, which are so numerous as to form the dense white clouds with which we are so familiar.

The simplest form of steam-engine is the injector (Fig. 50). It consists of a mechanical arrangement, by

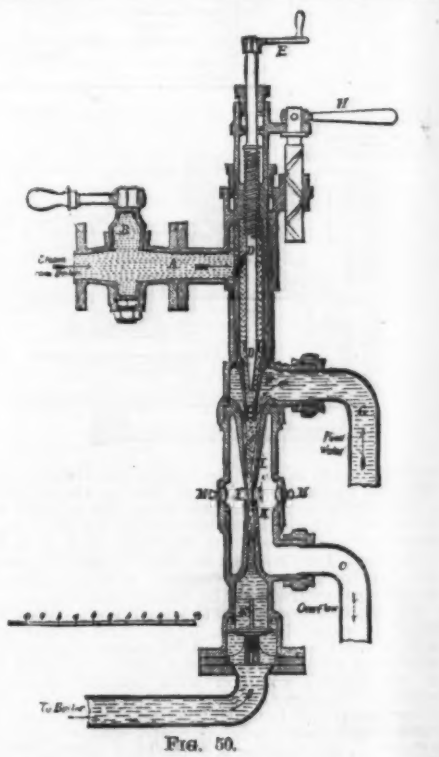


FIG. 50.

which a jet of steam is made to mingle with a stream of water which it warms in being itself condensed, after which the current of steam and water is delivered to a height, or under a pressure, depending upon the tension of the steam and the proportion of water mingled with it.

The apparatus in its most complete form is illustrated by the diagram. Steam enters through a pipe communicating with a nozzle, the orifice of which can be opened or closed by a taper spindle, which is made adjustable by a screw and hand-wheel. The nozzle itself enters a fixed outer nozzle, also of conoidal shape, and can be moved longitudinally, so as to vary the area of the annular space between itself and the fixed cone, the latter being connected at its upper end, by a branch pipe, to the water supply. The outer end of the fixed cone terminates in a chamber connected with the atmosphere, and opposed to it is a second fixed cone enlarging in the opposite direction. The outer end of this cone is guarded by a self-acting valve opening outward, and is connected to the delivery pipe. When steam is admitted through its nozzle, the jet issues into the fixed cone; and because this is of larger area, its velocity is reduced, and a certain amount of kinetic energy is rendered potential, just as we saw in the case of diverging pipes. The potential energy takes the form of a reduction of pressure in the water chamber, which at once causes water to flow and surround the

steam jet, which is immediately condensed, the water is raised some 60° in temperature, the velocity of the combined stream of condensed steam and water is reduced in proportion to the increase of weight, and enters the second cone, where the velocity is still further gradually reduced to $\frac{1}{4}$ by the diverging pipe, and its potential energy increased to such an extent that the liquid stream will rise to a pressure considerably greater than that of the boiler which supplied the steam. Let us take a particular case. The No. 8 injector has a steam jet 8 millimeters or 0·32 inch in diameter, and is the size usually supplied to locomotives. The feed water rises about 60° in temperature. We will assume steam at 100 lb. absolute pressure and 328° temperature.

The velocity with which steam, under these conditions, will discharge into the air is 2,593 feet per second, and the weight delivered will be 0·0549 lb. in the same time. Suppose the feed-water at 50°, then the mixture of steam and water will be at 110°, the water rising 60° and the steam falling in temperature 118°. The number of units of heat in the steam is 43·14, consequently, as the increase of the temperature of the feed is brought about at the expese of the fall of sensible heat, and of the latent heat in the steam, therefore, $60° \times x$ lb. water $= 43·14 \times 0·0549$ lb. $\times 0·37 \times 218°$. $\therefore x = 0·793$ lb., and the weight of the combined steam will be $0·793 + 0·0549 = 0·848$ lb. per second, and consequently the velocity will be reduced in the proportion of $\frac{0·055}{0·848} = \frac{1}{15·4} \times 2,593'$ or to 168·1 feet per second, and its kinetic energy will be $\frac{0·848 \times 168·1^2}{64·4} = 372·4$ foot-pounds.

The stream, endowed with this energy, would occupy much less space than the jet of steam, and therefore the throat of the receiving cone is reduced in diameter, and should, in this case, have an area of 0·0116 square inch only. The delivery pipe of the apparatus is about 1¼" diameter, or 151 times the area of the throat, so that the velocity of the water will fall to 1·11 feet per second, and its kinetic energy to 0·016 foot-pound, leaving 372·38 foot-pounds available for overcoming the pressure against which the water has to be discharged. The area of the pipe being 1·76 sq. in., and velocity 1·11', this energy would be absorbed if the water were discharged under a pressure of 190·6 pounds per square inch, so that an injector is competent to raise water to a much greater height, or deliver it under a greater pressure, than that of the steam which actuates it.

In this investigation I have made no allowance for friction eddies, and fluid contraction at the orifices; these make an appreciable difference in the calculations, yet results quite as high as I have indicated have been obtained. By reducing the proportion of water to the utmost, its temperature is raised, and its velocity, and therefore the kinetic energy of the combined current, is increased to such a point that one boiler has been made to feed another, working under twice the steam pressure.

The apparatus which is commonly called a steam-engine consists essentially of a vessel of cylindrical or spherical form, in which a piston works steam-tight, and receives from a boiler a supply of steam which pushes the piston either backward and forward, or round, in a continuous manner.

Steam-engines may be divided into three classes: One, in which a piston reciprocates longitudinally in a cylinder, and receives the impulse of the steam on one side only, or alternately on both sides; second, where the piston reciprocates about the longitudinal axis of the cylinder; and finally, into the whole class of rotary engines, in which the motion of the piston is more or less continuous. The time at my disposal will only permit me to dwell on the first class, which is most common, and by far the most important; but the general principles which I shall explain apply equally to all.

Reciprocating engines may be single or double acting, and have vertical, horizontal, or inclined cylinders; but in all cases the pistons work steam-tight longitudinally in truly bored cylinders, and transmit the energy imparted to them—by means of piston-rods working through packed glands in the cylinder covers—more or less directly to the work has to be performed. The distribution of steam is managed by valves of various forms, actuated automatically by an endless variety of motions; but in all cases steam is admitted at the commencement of a stroke, allowed to flow in for some portion of it, then shut off and permitted to expand. When the end of the stroke is nearly reached, a passage is opened, by means of which the imprisoned steam is allowed to escape either into the air or into a condenser. In the latter case, it is cooled down by means of a current of water to as low a temperature as possible.

Steam cylinders are sometimes surrounded by a jacket, the space between which and the inner lining is filled with steam at the boiler pressure, and sometimes they are not so constructed, but merely covered, more or less completely, with some non-conducting material.

In double-acting engines the cylinders, at every complete revolution, have each end filled with steam of the temperature due to its pressure, and the quantity of heat imparted to the metal is so great that a uniformity of temperature is kept up, notwithstanding the variation of pressure in the steam.

When the cylinders are steam-jacketed, the temperature of the working substance is not only maintained, but the pressure is frequently increased, by the evaporation of water, which may be diffused in the steam or have been carried over from the boiler. For reasons connected with the practical construction of engines, the pistons never sweep through the whole volume of their cylinders; at each end there is a space, representing a small clearance between the surface of the piston and the cylinder cover, added to the volume of the ports and passages, the aggregate usually amounting to from 1' to 2' of the length of the stroke.

According to what law do the steam pressures vary with the variation of volume? If the temperature of liquefaction of steam were further removed from the ordinary temperature which surrounds us, and if the working substance could be prevented from receiving heat while expanding, the pressures would vary according to the ordinates of an adiabatic curve; but, as I have already explained, that cannot take place, because the slightest fall in temperature causes a small portion of steam to revert to the liquid state, and the heat so set free raises the rest of the steam in temperature. In addition, because steam is a good radiator and absorber of heat, the hot sides of the cylinder and piston warm it very quickly, so that, in an unjacketed cylinder, the pressures vary very nearly as the ordinates of an isothermal curve.

We must now invoke the aid of the indicator diagram, to tell us what actually takes place inside the cylinder. On the wall is a diagram, A (Fig. 51), taken from a condensing steam-engine, having an unjacketed

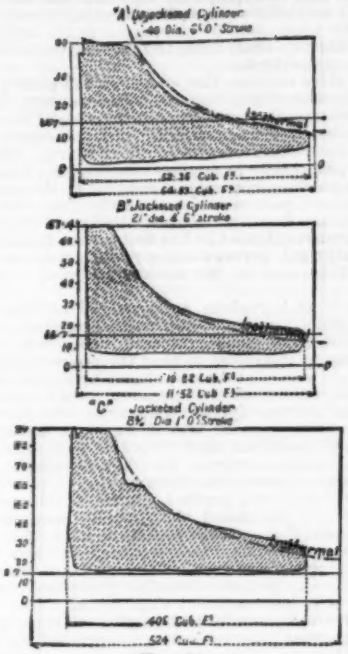


FIG. 51.

cylinder, 40 in. diameter by 6 ft. stroke. The volume swept through by the piston is represented by the length of the diagram, and amounts to 52·35 c. ft., while the total volume, which includes the clearance at each end, is represented by the vertical lines beyond the figure at each end, and amounts to 54·89 c. ft. The lowest horizontal line represents absolute zero of pressure, that is, absolute vacuum, and the ordinates the absolute pressures per square inch. The horizontal line marked 14·7 represents the standard pressure of the atmosphere. The upper horizontal line represents the initial steam pressure in the cylinder, and the point where the figure suddenly falls away from it indicates the spot where the steam-valve closed, and the steam commenced to expand. At the end of the stroke, the figure drops suddenly again. This marks the point where the valve, communicating with the condenser, opens and allows the imprisoned steam to escape. The lower line of the figure registers the "back pressure," as it is called, that is, the tension of the steam in the condenser, and, finally, the sudden rise of this line indicates the point where steam is again admitted, and the cycle completed. I have dotted in the isothermal curve; you see how closely it follows the curve traced by the indicator; the temperature of the steam, therefore, has not varied, hence the heat converted into work must have been derived from the heat communicated to the metal of the cylinder and piston during the time that steam was entering. This could only take place by the condensation of a small portion of the steam.

Let us give this action a numerical value.

We have seen that the work done in expanding along an isothermal curve is = pressure per square foot × volume of agent used × the hyperbolic logarithm of the ratio of the total volume to the volume used, or let P_1 = pressure per foot square, V_1 volume used, V total volume of cylinder, then work

$$= P_1 V_1 \log^e. \frac{V}{V_1}.$$

But in a steam-engine, the piston is moving and doing work all the time the steam is being admitted, and this work $= P_1 V_1$, therefore the total work will be the sum of the two

$$= P_1 V_1 \left(1 + \log^e. \frac{V}{V_1}\right),$$

supposing a perfect vacuum to exist; but as this never is the case, and in non-condensing engines the pressure which opposes the return of the piston is even a little higher than one atmosphere, we must deduct the work done against back pressure. To ascertain this, the mean back pressure must be measured off the diagram; let us call it p per square foot, then the work done will be pV, hence the net work will be

$$P_1 V_1 \left(1 + \log^e. \frac{V}{V_1}\right) - pV.$$

In the particular case we are dealing with—

$$W = 40·5 \text{ lb.} \times 144 \text{ sq. in.} \times 13·09 \text{ c. ft.} \times \left(1 + \log^e. \frac{52·35 \text{ c. ft.}}{13·09 \text{ c. ft.}}\right)$$

$$- 3·8 \text{ lb.} \times 144 \text{ sq. in.} \times 52·35 \text{ c. ft.} = 153·354 \text{ foot-pounds,}$$

which agrees very closely with the actual area of the diagram, measured either by scale or with a planimeter.

Since the pressures, in expanding, have varied as the ordinates of an isothermal curve, it follows that the temperature of the steam has not altered, and, consequently, none of its heat has been converted into work; but the heat which has been so converted must have been derived from an extra volume of steam, which was condensed by the relatively cold surfaces it came in contact with, which surfaces again give it out as the volume of the steam increased, and so kept up the waste caused by the conversion into work; in other words, the surfaces of the cylinder acted as carriers of heat from the boiler to the expanding gas. We can easily calculate the quantity of steam condensed.

The work done in each stroke we have seen is 153,354 foot-pounds, corresponding to 198·6 units of heat. The total heat of steam at 40·5 lb. pressure and 268° temperature is 1,163 units, and as the condensed steam remains at the same temperature, the available heat is $1,163° - (268 - 32) = 927°$; therefore, the weight of steam condensed to supply the heat converted into work will be $\frac{198·6°}{927°} = 0·214$ lb. Now, the total volume of steam let into the cylinder up to the point of cut off, was $\frac{54·89 \text{ c. ft.}}{4} = 13·72$ cubic feet, the weight of which,

$$= \frac{13·72 \text{ c. ft.} \times 62·2 \text{ lb.}}{641 \text{ c. ft.}} = 1·329 \text{ lb.}$$

adding to this the weight condensed, we have 1·543 lb. of steam used per stroke. But of this only 0·214 lb. is converted into work, so that the duty is only $\frac{0·214}{1·543} = 0·14$, or 14 per cent. The mean back pressure was 3·8 lbs., and in the condenser the temperature would be that due to the pressure, or 151° = 611° absolute, while the initial temperature is 268°, or 728° absolute, so that our agent is working between these temperatures, and hence, according to Carnot's doctrine, the duty could not exceed $\frac{728° - 611°}{728°} = 16$ per cent., which differs by only 2 per cent. from the duty derived from estimating the comparative weight of steam required for filling the cylinder, and for actual conversion into work. This difference probably arises from the uncertainty as to the temperature of the exhaust steam in the cylinder. It is sure to be higher than that in the condenser, because the hotter surface of the cylinder and piston would warm it up. If t be the true absolute temperature, then $\frac{728° - t°}{728°} \left\{ = 0·143 \right\} t° = 624°$; that is, the steam would be 13° hotter than the temperature absolutely necessary to maintain its pressure—which is very likely to be the case.

Fig. 51, diagram B, is an indicator diagram from a condensing-engine with a vertical cylinder 21 in. diameter by 4 ft. 6 in. stroke, the surfaces jacketed all over. The dotted line is the isothermal, and you notice that the true pressure curve rises above it toward the end of the stroke. The same remark applies to diagram C (Fig. 51), taken from a portable non-condensing engine having a cylinder 5½ in. diameter by one foot stroke, also jacketed all over. Inasmuch as the steam in the jackets is at the same pressure and temperature as that admitted to the cylinders, it follows that the rise of pressure above the isothermal cannot be due to an increase of temperature, but must be caused by the evaporation of water carried over by the steam from the boiler. In these cases the heat converted into work has been derived from the steam in the jackets, transferred by radiation and convection from the metal of the cylinders; the condensed steam withdrawn from the jackets would, therefore, represent the quantity of heat converted into useful work. When the steam pressure becomes considerable, and a large range of expansion is aimed at, a single cylinder becomes so large, and the strains so severe, that it is more convenient to arrange for the steam to expand in two or more cylinders successively. Engines constructed on this plan are called "compound." The cylinder into which the steam first enters is the smallest; it exhausts into a large one, and this again into one still larger, and so on. Diagram D (Fig. 52) illus-

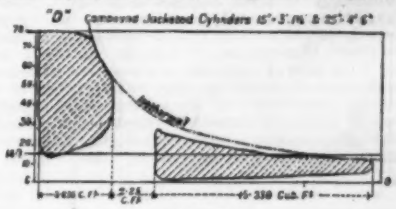


FIG. 52.

trates the action which takes place. The figure on the left-hand has been traced from the high-pressure cylinder of a double cylinder engine. It has a working volume of 3·835 cubic feet, or with clearance 4·427 cubic feet. 2·75 cubic feet of steam at 78 lb. absolute pressure were admitted during the down stroke; the upper line indicates the pressures which resulted till the valve was opened to permit the steam to flow into the low-pressure cylinder. This had a volume of 15·338 cubic feet, or 16·420 cubic feet with clearance.

Between the two cylinders the connecting pipe, valve chest, and clearances have a capacity of 2·35 cubic feet. The two cylinders are coupled, so that the pistons travel simultaneously in the same direction, so that the steam from the top of the high pressure cylinder completes its work in the bottom of the low, during the up stroke. While this is going on, the two cylinders are in communication, and the volume occupied by the steam is constantly altering, the capacity of the small cylinder decreasing, that of the large increasing, the connecting space between remaining constant. The figure on the right hand side is that traced by the indicator with the base line made proportional to the volumes successively occupied by the steam. The dotted line is the isothermal. It follows exactly the expansion curve of the high pressure diagram, and again touches the curve of the low pressure figure at the end of the stroke, but there is a considerable divergence at the commencement of the low pressure stroke, caused partly by the cooling of the steam in traversing the unjacketed connecting passages between the cylinders, and partly by the resistance of friction and eddies in the passages. This loss is, however, ultimately made up by the heat imparted by the steam jackets of the cylinders. In both cylinders there is negative work; in the high pressure it is the reaction to the pressure on the low, and is equal to the total work done in the latter, reduced in the ratio of the volumes of the two cylinders, and in the low pressure it is the resistance of the imperfect vacuum in the condenser.

A practical illustration of the work done by the

steam condensed in the jackets, we may find in the case of a pair of pumping engines at the Lambeth Waterworks, Brixton.

These engines were found to consume 16·8 lb. of steam per horse power per hour in the cylinders, and 2·8 lb. in the jackets. Steam was at 54·4 lb. pressure, or 69·1 lb. absolute and 302° temperature.

The total heat of 1 lb. of steam under these conditions is 1,174° from the freezing point; hence, as the steam was condensed to water at very little below its own temperature, the heat parted with was 904° per 1 lb., corresponding to work per minute

$$\frac{2{\cdot}8 \text{ lb.} \times 904 \text{ lb.} \times 772}{60} = 32{,}569 \text{ foot lb.},$$

which is a little less than a horse power.

The duty done by 19·6 lb. of steam per horse power per hour was therefore represented by the 2·8 lb. condensed $= \frac{2{\cdot}8}{19{\cdot}6} = 0{\cdot}142$.

The range of temperature could not have been more than 149°, that is from 302°, the initial temperature of the steam, to that of the condenser, corresponding to 4 lb. average back pressure, say 153°; hence the duty would be, according to Carnot $= \frac{149°}{762°} = 0{\cdot}195$, about 5 per cent. more than in my previous estimate, the discrepancy being due, as I have already pointed out, to the uncertainty as to the temperature of the steam in the cylinder on the vacuum side.

The work of pumping out the mixture of condensed steam and water against the atmospheric pressure in condensing engines, and of pumping feed water into the boiler in all engines, should be deducted from the available work indicated by the diagrams.

From the four cases which I have cited, you will see that steam does not differ from air in a hot air engine, or from the mixture of gases in a gas engine, in being merely the agent of transforming a certain amount of heat imparted to it into useful work. The circumstance that we have to manufacture the agent from its liquid state at great cost is a disadvantage, because we cannot utilize much of the heat so expended, and is also the cause why, in steam engines, the useful effect obtained necessarily bears so small a proportion to the total energy imparted to the agent in its liquid form.

It is difficult to realize the proposition that the gases used as agents in heat engines have no influence on the proportion of heat converted into work. The truth is, that their function is similar to that of a train of wheelwork, or of a lever, in transmitting a mechanical effort. A common lever used for the purpose of raising a weight is an agent by means of which a force is caused to perform certain work, but the lever itself has no influence at all on the result. Provided the length of the arms is kept at a constant ratio, the action will not be affected by the lever being short or long, light or heavy, of wood or of iron. There is, however, this difference between the lever and the gaseous agent, namely, that the former can be used over and over again, without in any manner deteriorating or changing its nature, consequently its first cost is not of much moment in comparison with the work it is capable of transmitting; but the gaseous agents have to be produced and thrown away in each cycle, hence their first cost, that is, the cost of generating steam or heating air, is of great consequence, and it is upon the economy with which the agents are produced and used that efficiency of heat engines depends. Now the weight of the agent used, in proportion to the power developed, decreases with the increase of the range of temperature through which it works and with the increase of the rate of expansion, hence the efficiency of steam engines depends on the initial pressure, and therefore temperature of the steam and upon the number of times it is caused to expand. To illustrate this fact graphically, I have prepared a diagram (Fig. 53) showing, by means of curves, the volume and

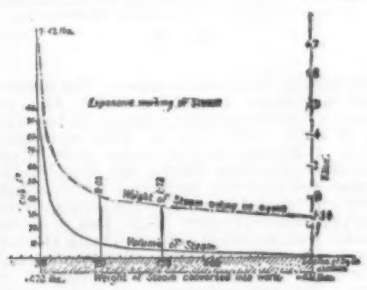


Fig. 53.

weight of steam required to yield 378,720 foot-pounds of work in a cylinder of 100 cubic feet capacity, with a back pressure of 3·7 lb., and steam pressures ranging from 30 lb. to 300 lb. absolute. At 30 lb. pressure, without any expansion, the required work is produced at an expense of 7·42 lb. of steam. At 100 lb. pressure, 8½ cubic feet, weighing 1·96 lb. expanding along the isothermal, will produce the same result; and at 300 lb. = 2·09 cubic feet, weighing 1·34 lb. You will observe how rapidly an economy is effected up to about 100 lb. pressure, cutting off at 8½ per cent.; after that the economy increases much more gradually, so that a point will soon be reached in practice where the mechanical difficulties connected with the use of steam at high pressures and temperatures will no longer be balanced by a saving of fuel.

The dotted line under the base shows the weight of steam, the heat in which is actually necessary for conversion into work; this quantity is nearly constant, being a little greater at the lower pressures. Between 90 lb. pressure and 150 lb. there is, according to the diagram, a reduction of steam used from 2·05 lb. to 1·72 lb., a saving of 16 per cent. Mr. List, chief engineer of the Donald Currie Line, has sent me some valuable information respecting the effect which an increase of pressure with corresponding increase of temperature and rate of expansion, obtained by the introduction of treble expansion engines, has had in the economy of fuel. An ordinary double cylinder compound engine, working with 90 lb. pressure, consumed 1·59 lb. of coal per horse power per hour; the treble cylinder compound, under 150 lb. pressure, consumed only 1·3 lb., a gain of 18 per cent., which agrees pretty well with the theoretical estimate.

The pressure of steam acting on a piston, if the latter is free, as in a Cornish pumping engine, produces accelerated motion of irregular velocity depending upon the rate of expansion, and this has to be very carefully adjusted so that the retarding forces, consisting of the work done by the engine in the down stroke and its friction, shall bring the moving parts to rest at the end of the stroke.

In rotative engines, the speed of the piston is controlled by the crank, but still it is necessary, in order to insure smooth working, that there shall be a certain relation between the accelerating force acting on the piston, the weight of the moving parts, and their velocity, especially in engines running at a high speed, and it is possible so to adjust them that the work done in the second part of the stroke, when the reciprocating parts are coming to rest, shall just balance the energy communicated in the first part. If matters are not so adjusted, severe pressures are produced at the turn of the stroke on the various portions of mechanism.

There is an ingenious arrangement of balanced engine in which two cylinders are set opposite to each other, with their pistons connected to cranks also opposed one to the other, so that the reciprocating parts are always moving toward or receding from each other. In consequence of this disposition, when the weight moved by the two cylinders is alike, the strains due both to steam pressure and momentum balance each other in all positions, and the crank shaft has only the torsional strains to carry. The diagram on the wall represents a compound condensing engine of this kind, arranged to drive a vertical spindle centrifugal pump.

I have now completed the task imposed on me by the Council of the Society of Arts, and have, to the best of my ability, laid before you the modern theories connected with the conversion of heat into useful work. Those of you who have attended the whole course of lectures will have noticed that my aim has been to demonstrate, by practical examples of the most varied kind, the great principle, first enunciated by Carnot, that in the conversion of heat into work the duty obtainable from the working substance is a function of the fall of temperature alone, and I trust that in doing so I have succeeded in impressing you with the conviction that the doctrine is not a mere algebraical expression, but is a real, living principle, the application of which will indicate with certainty the limits within which we can hope for improvement, and the direction in which that improvement must be sought.

THE SUN'S WORK.

A NEW THEORY OF RADIANT HEAT.

By F. Jarvis Patten, U. S. A.

Go out any clear night and study the vault of heaven, try to imagine our earth an incandescent globe or sun pouring forth its rays of heat into space in every direction. These rays would be vertical lines at the surface of the earth, diverging more and more from each other as they swept away into the voids of space.

Select a single star that sends its feeble ray unto the earth, and picture it our own sphere revolving about the central luminary.

Consider for a moment how little of the heat radiated from our imaginary sun would fall upon that distant star as compared with the infinitely greater part that would be speeding past, forever lost in the depths beyond. Select seven other stars on the same great circle of the heavens, and they will represent the different bodies of our solar system coursing about this imaginary sun, our earth. Collect all the heat arrested by those eight distant points in space, and conceive if you can how insignificantly small a part would be intercepted by all those bodies as compared with that which would escape them all. Consider also that in each of those far-off planets all motion, all force, all life, is momentarily dependent upon the feeble ray that comes to it across the depths of space; that were the central mass to cease his shining for a single day, all life in those distant orbs would cease, while they would roll along their endless paths in the darkness of eternal night.

But if our accepted views of the sun be true, we are forced to believe that his radiant heat, which is the force, the light, and life giving power of all this system, is being thus continually dissipated into space in the proportion of millions upon millions of parts that are lost for every single part that is converted to use in the surrounding planets. Does not so great a profusion of waste seem inconsistent with that perfect arrangement of order and of law, a scheme of absolute arithmetical quantivalence elsewhere apparent on every hand, and which forbids alike the loss of a single atom of matter or a single unit of force?

Such, however, are the views of the sun's daily work that we have inherited from the past, and such our accepted views to-day.

Can one thus contemplate the physical aspect of our planetary system without perceiving that our present views are clumsy and unreasoning, better adapted to an age when to be simply incomprehensible was to be sublime?

In every field of terrestrial research the thought of the past century has had a single, unvarying tendency, a tendency to show that every motion, every force, in the physical universe of force and matter is subservient to a single law, the law of equivalence, by which we know that no force is lost, but only changed in the form of its manifestation or appearance. Alone in the field of solar physics are still accepted the views of an old philosophy, whose tenets have been weeded from every other line of scientific inquiry.

To many, our views of the sun have doubtless seemed vague, inadequate; but it is one thing to show wherein existing theories are weak, but a long step beyond to point the way to a better; it is one thing also to conceive a theory, but a task far more difficult to either prove it or to so present it to others that the assumed hypothesis will have value with them.

To regard it in the same light, they must at least consider it from the same standpoint, and to do this requires in a measure the same way of seeing.

It has occurred to the writer that an extension of the principle of "the conservation of energy," which finds so beautiful an application in all the mutual interchanges of terrestrial force, should be signally applicable to the interaction of all the forces of a single independent system of whatever character, considered as a whole.

To do this and to render the application intelligible it will first be necessary to review the physical and astronomical bearings of the problem; the first brings us to a consideration of

THE ACCEPTED THEORIES OF THE SUN.

A popular writer and lecturer in describing the "Seeming Wastes of Nature" accepts the fact of a continued and ceaseless outpouring of the sun's radiant force in every direction, and pictures all suns as vast reservoirs of stored energy throwing light and heat quite aimlessly into surrounding space, as were the little that might impinge upon surrounding planets a mere coincidence of chance.

In one passage he says: "Our earth receives less than the two hundred millionth part of the light and heat emitted by the sun," which amounts to saying that it receives virtually nothing when compared to the entire amount the sun emits, and "the rest," he says, "seems uselessly scattered through interstellar space; *how enormous, then, in accordance with our conceptions, must be the waste of force!*"

Such a picture well portrays the seeming wastes of nature, and certainly seems widely at variance with our accepted doctrine of the conservation of energy and the correlation of forces.

Another prominent authority also accepts this same state of things, which he sums up and illustrates as follows:

"If the sun were surrounded by a solid sphere of a radius equal to the mean distance of the sun from the earth, the whole of this prodigious amount of heat would be intercepted; but considering the earth's apparent diameter as seen from the sun is only seventeen seconds of arc, the earth can intercept only the 2,250,000,000 part of this heat." Assuming that the other planetary bodies swell the amount of intercepted heat to ten times this quantity, there remains the important fact that

$$\frac{224{,}999{,}999}{225{,}000{,}000}$$

of the solar energy is radiated into space, and apparently lost to the solar system, and the one two hundred and twenty-five millionth part only ($\frac{1}{225{,}000{,}000}$) is utilized or intercepted, . . . and the question forces itself upon us how this great loss can be sustained without producing a noticeable diminution of the solar temperature, even within the limits of a human lifetime."

It is due the author, Sir William Siemens, from whom the above quotation is taken, to state that these figures were given by him in an article which he styled "an attempt to open a debtor and creditor account with the sun," being, as he confessed, dissatisfied with that conception of our system which admits of such a wholesale waste of force, and conceiving a plan by which the immense quantities of heat apparently wasted in space might be returned to the central luminary, and continually renew the energy of his radiation.

While the overwhelming nature of this great outpouring of energy from the sun has continued to excite our wonder, and while science has made within a few years such wonderful progress in every line of research, the source of the sun's energy, being, so to speak, such a remote consideration, has had the attention of comparatively few, and who for the most part have been contented to follow in the old ruts, and little of a general character has been added to the solution of the problem which now stands foremost among those unsolved to-day.

Existing theories on the subject are the accepted theories of the past strained and distorted to accommodate them to the facts that have from time to time been elucidated in the domain of solar physics; and while we have acquired within comparatively recent times entirely new conceptions regarding force and matter, this question of the sun alone seems to have remained, in a great measure, where the science of the 18th century left it, for the sun to-day is still regarded as it was more than a hundred years ago, a burning gas ball in the heavens, burning but not consumed; shedding boundless stores of heat and light into surrounding space in all directions in a profusion of waste that beggars all description.

A glance at the more prominent of the different theories that have been advanced to account for the sun's radiation will make this clear.

That magnificent conception, the Nebular Hypothesis, which we owe to La Place, accounts for the present condition of the solar system upon the theory of the gradual subsidence toward a nucleus of attraction of a vast nebula of comparatively homogeneous density and indefinite extension, drifting through space in the form of a vast cloud of highly attenuated cosmic vapor. The theory presumes this condensation to have taken place under the action of weight impressed upon its elements by their reciprocal attractions for each other, and that the *living force* with which this vast amount of matter would reach the terminus of a fall so great as to transfer it from far beyond the distant orbit of Neptune to its present abode, the sun, would impress upon the condensed mass the most intense molecular agitation, whence our heat. "The system is now in a state of cooling, and the sun's host is now living its lease of planet life in the radiating waves of energy which constitute that apparently endless stream of solar effulgence whose loss through waste the theory presumes to be so slight as to require countless ages to bring the solar molecules to a state of rest, and convert the sun into a cold, non-luminous mass."

A theory to account for the sun's continued agitation, which has perhaps been more credited than any other of recent times, asserts the existence of a continued meteoric rain upon his surface. It supposes the depths of space filled with scattering bodies, from the size of a grain of sand to that of a planetoid, wandering as guided by the most effective attractions, until, coming within the limits of the sun's attraction, they are drawn to his surface at a high velocity, and by their continued shocks of impact keep up that intensity of heat which

the sun appears to maintain undiminished. This theory, which has perhaps created more discussion than any other, supposes the sun subject to a constant bombardment of matter from surrounding space, and has evidently had its origin partly in the nebular hypothesis and partly in the evident necessity of discovering some plausible means by which the high temperature of the sun might be supposed continually renewed, and the apparent necessity for this of some great heat-generating force. It has a formidable rival in the ingenious hypothesis advanced by Helmholtz to account for the continuance of solar heat by the shrinkage or gradual reduction of the sun's volume; chemical action between the different parts of the sun has also been suggested, and set aside as inadequate.

Many other theories of recent date, but of a still more speculative character, have been advanced and discussed, but have so far added comparatively little to exact knowledge; some assume that the body of the sun is entirely gaseous, others that it is partly fluid, and others still that it has a cold, solid, and even habitable nucleus. All agree, however, in regarding the sun in some sense as a vast fire ball burning in the heavens, and radiating his heat into space in much the same manner as would a ball of red hot iron suspended in the midst of an empty room.

It requires no special intuition to discern the various objections peculiar to each of these theories; the answers to them all are more or less familiar. As regards the meteoric rain, it would seem that if the sun is fed by meteors, so profuse in number and of such density as to maintain his molecular agitation, the earth and other planets in their revolutions about him would be continually intercepting a portion of this shower and would receive a large amount of heat from this source, and which does not appear to be the case. Again, if the sun's heat be attributable to the presence of matter in any considerable amount in space, such a quantity would sooner or later have its effect upon planetary motions. That the earth has not been so affected is now quite evident, while our testimony to this fact is of continually increasing strength. On this point Prof. Cerk in a published lecture says: "Our planet is rushing in its orbit around the sun at an average rate of over 1,000 miles a minute, and completes its annual journey of some 550,000,000 miles in 365 days 6 hours 9 seconds and $\frac{6}{10}$ of a second! Mark the tenths, for astronomical observations are so accurate that if the length of the year varied permanently by the tenth part of a second, we should know it, and if there were a medium in space which offered as much resistance to the motion of the earth as would gossamer threads to a racehorse, the planet could not come up to time, year after year, to the tenth of a second." To all these theories as a class stands also the objection that eventually this aggregation of matter would so materially increase the sun's mass as to affect noticeably the periodic times of the planets in their revolutions about that body, and which has apparently not happened.

There is one more theory which claims our attention, and which, as already mentioned, is distinguished as perhaps the best if not the first attempt to open what its author calls "a debtor and creditor account with the sun," and according to which the radiant energy, which is now regarded as dissipated in space, could be arrested and brought back in another form to the sun, there to continue the work of solar radiations.

Its details are too involved for our present consideration, but, right or wrong, it marks a first, highly authorized attempt to abandon the old views, and shows the eminent physicist's dissatisfaction with the old theories that suppose such a wholesale waste of force, none of which are in keeping with the recent doctrine of the conservation of energy, but on the contrary are in direct violation of it.

A consideration of the views thus accepted shows them one and all exhaustive in their nature, with the single exception of the last one cited, while none of them admit of more than two or three of the planets of our system being inhabited; and these results follow from the doctrine that the energy required by the entire system for its maintenance is being dissipated in empty space, leaving but a small amount to impinge upon the planets for whose existence, and the preservation of whose life, this vast machinery was presumably designed.

Having thus briefly reviewed the existing theories of the sun's radiation, let us turn our attention for a moment to the astronomical phase of the question, and endeavor to conceive what these theories, one and all, represent the sun as doing; this involves

A CONSIDERATION OF PLANETARY SPACE AND THE BODIES OF THE SOLAR SYSTEM.

Few readers of popular astronomy form a correct idea of the relative sizes of the planets and the space dimensions of the solar system, and but little account is taken of the immense voids of space through which they sweep in their journeys about the sun. These considerations are passed at a single stride as we are hurried from a bewildering contemplation of one planet to that of another, and that space whose depth and breadth is beyond the mind to conceive is crossed with the swiftness of thought.

The whole scheme is one so vast in its design, so gigantic in its proportions, that the mind is baffled in its attempts to grasp the magnitude of space; and the planets are so small when compared to their relative distances apart, that anything in the nature of a graphical representation, with here a circle to represent the sun, and there another to represent the earth at its proportionate distance from the former in respect to its size, becomes impossible, and gives only erroneous impressions. Any attempt at a pictorial representation to scale is futile. A map so large that the earth would have on its surface a diameter of a quarter of an inch would, in order to represent the planet Neptune in its proper size and place, be a mile and a half in length.

Such a picture is not possible; in lieu of it the mind is generally taxed with an array of figures that convey to the mind but little idea of the distance it is desired to represent. It is impossible to conceive a million miles, and a hundred million gives no different picture. The earth sphere is but a speck in space, and when in imagination we plunge into its void and seek with the eye of the mind to form some picture of its vast extent, we are without a suitable measure to be used as a standard of comparison.

On the earth, by heaping up the tens, hundreds, and thousands of figures, we find the mile a unit sufficiently large for the measure of the lengths and areas of its surface; but in the vast deep, where the earth dwindles to a speck absolutely insignificant, having when compared to its surroundings only the dimensions of a single mathematical point, that unit with which this point was measured in thousands is of little use to span the void that separates one planet of our system from its nearest neighbor. It is the same as though we were to express the distance that separates two cities in terms of a pin's point, so great is the magnitude of that space which separates one sun from his nearest companion, one system of worlds from its nearest neighbor.

The solar system, quite infinitesimal in the stellar universe, is that to which our studies of the whole must be confined, and this, when contemplated by itself and viewed from our contracted standpoint, seems also bewildering in its magnitude, and its small bodies seem widely separated from each other and from the central mass.

Passing from the sun outward, we find these bodies at varying and at the same time rapidly increasing distances away; how, then, shall we formulate a picture of this vast system which shall convey to the mind some idea of its vast extent, for difficult as it is to conceive the relative sizes of the planets, it is far more so to place them in the mind at their proper relative distances from the sun. A common illustration is perhaps best adapted to our purpose.

Picture, then, on a vast level plain a globe 10 feet in diameter, to represent the sun, and about 1,000 feet away, or 333 yards, a little globe one inch in diameter, about, would represent our earth.

Six miles from the central globe a ball about 4½ inches in diameter represents the planet Neptune, the outermost body of the system.

With this hasty glance at the relative sizes and places of two bodies of our system, we cannot fail to be impressed with the comparative insignificance of our earth when we endeavor to imagine the stated distances increased to their real dimensions.

What, then, is the relative importance of the position the earth holds in space, and what is its capacity for arresting and converting to its use that constant stream of radiant heat the sun seems forever pouring into space?

To ascertain this roughly, conceive a vast spherical shell having the sun at its center and its surface at the distance of the earth; what part of this entire surface would be the disk or circle the earth presents to the sun?

The comparison bids fair to launch us into a sea of figures, but which may be avoided by using the miniature system we have just pictured, in which the earth is located at a thousand feet from the central globe, and Neptune is six miles away.

The ball assumed to represent the earth would present to the miniature sun a disk one inch in diameter, and its area would therefore be less than one square inch, while the encircling shell, whose radius is a thousand feet, would have a superficial area of nearly half a square mile, or 320 acres. Such is, then, the ratio, 1 square inch to 320 acres, that the earth disk presents to the sun, as compared with the vast space surrounding the sun at our distance from it, and in which no surface is presented to absorb its rays of heat and light. At Neptune these surfaces would be as 12 square inches to 430 square miles, or more than a quarter of a million acres. Let us consider for a moment the meaning of these comparisons.

For every 12 square inches that the disk of Neptune presents to the sun, for every such surface there must be more than a quarter of a million acres in the surface of the sphere at his distance. Does not the picture lead us to a conclusion of almost irresistible force?

In view of the commonly accepted views of the sun, these comparisons mean, first, in the case of the earth that for every single square inch the earth presents to intercept the solar ray as it flies into space there are for every square inch so presented 320 acres of unoccupied space in every inch of which the same amount of heat is flying past, lost in the stellar depths. For the remote planet Neptune, the comparison says that for every square of 12 inches area exposed to the solar ray, a quarter of a million acres are similarly endowed apparently to no purpose.

However tedious the foregoing figures may have been, are they not a necessary step if we would consider the great system of the sun as it is in space?

Do they not serve to render apparent in the most striking manner that, according to accepted views, the sun must be hourly, daily, pouring his radiant force into the depths of space in the proportion of millions lost for every part that is rendered available for the maintenance of planet life?

It is either thus as shown, or else, through the agency of some yet undiscovered law, this life-giving principle, which is at once the beginning and the end of all force, *must be transmitted*, not as we have generally supposed freely in all directions into the voids of space, *but from the central sun to the surrounding planets direct, and to them alone*, and in such a manner as to render its effect in its field of operation, the planet, entirely independent of planetary space around beyond.

It is the purpose of our theory to place this assumption upon a plausible and rational basis. It is our purpose to show how the sun's heat, his radiant force, may be carried direct to the earth and the other planets of the system, and that it is not scattered aimlessly into space as we now suppose.

The hypothesis has been advanced before in a vague and indeterminate way; but how it could be possible without reference to or the assumption of mysterious forces, of which we know little or nothing, has not been apparent.

It will be the purpose of our theory to place the assumed hypothesis on a plain *mechanical basis*, which shall be at once in keeping with the known laws of exact science and contrary to none of them.

THE CONSERVATION OF ENERGY.

So long as our philosophy is wanting in the elaboration of a single vital truth of nature, so long will the speculative faculty find honorable and lofty work in searching the path of a new departure to find the opening to that wider field of thought, the clearer and broader comprehension of those truths which underlie the gigantic fabric of the material universe.

It is in the elaboration of these truths that the human mind has ever found its noblest occupation; and on the battlefields of science the martyrs in the cause of truth have contributed far more to the advancement of the human race than the thousands who have fallen in the maintenance of opinion. Such has been the history of the past, and such will be the work of the future until the seekers after truth shall demonstrate in its perfection the reign of law.

The nineteenth century has been the silent witness of one great step in this direction, an achievement so magnificent in its importance, so universal in its bearing upon subsequent work, that it deserves to rank with the principle of universal gravitation, than which none can be more sublime in grandeur of conception.

This great truth, known as the principle of the conservation of energy, is so pregnant with meaning that it seems to comprehend the combined truth of all mechanics in a single enunciation.

Science is a growth, a development of law, and from the time when the "Prince of Philosophers," Faraday, guessed at the law of conservation of energy in his prediction of the correlation of the physical forces of nature, to the present, one step added to another has finally placed its truth among the accepted axioms of science.

It was Faraday who said: "I have long held the opinion, amounting almost to conviction, that the various forms under which the forces of matter are made manifest *have a common origin*, or, in other words, are so directly related and mutually dependent that they are *convertible*, as it were, one into the other, and possess equivalence of power in their action."

It was not, however, until Joule had demonstrated by unquestioned experiment the value of the mechanical equivalent of heat that was fully realized the importance of this principle of the correlation of forces upon which the transformation of energy thus dimly foreshadowed in Faraday's prediction now finds a secure foundation.

This truth, so replete with promise for the future, teaches that "throughout the material universe there exists a constant, unvarying total of force, among the myriad of whose component parts the most varied interchange and fluctuation is constantly going on."

In the mutual convertibility of the different expressions of force, as evinced in nature about us, lies interesting proof of their identical origin. The lifted weight is the common and familiar form of illustrating the transformations of energy, both on account of its simplicity and because of its manifest parallel to so many of the varied and unceasing changes of nature on every hand.

To borrow an illustration from Tyndall, comprising a more general application of the same principle, he says:

"The sun warms the tropical ocean, converting a portion of its liquid into vapor, which rises in the air and is recondensed on the mountain heights, returning in rivers to the ocean whence it came. Up to the point where condensation begins, an amount of heat exactly equal to the molecular work of vaporization and the mechanical work of lifting the vapor to the mountain height has disappeared from the universe.

"What is the gain corresponding to this loss?

"It will seem, when mentioned, to be expressed in a foreign currency. The loss is a loss of heat. The gain is a gain of distance, both as regards masses and molecules. Water which was formerly at the sea level has been lifted to a position from which it can fall; molecules which had been locked together as a liquid are separated as vapor that can recondense.

"After condensation, gravity comes into effectual play, pulling the showers down upon the hills, and the rivers thus created through their gorges to the sea. Every rain-drop which smites the mountain produces its definite amount of heat; every river in its course develops heat by the friction of its bed. In the work of condensation the act of vaporization is accurately reversed.

"Compare, then, the primitive loss of solar warmth with the heat generated by the condensation of the vapor and the subsequent fall of the water from the cloud to the sea; they are mathematically equal to each other.

"No particle of vapor was formed and lifted without being paid for in the currency of solar heat; no particle returns as water to the sea without the exact quantitative restitution of that heat.

"*There is nothing gratuitous in physical nature.* No expenditure without equivalent gain; no gain without equivalent expenditure.

"*Has this uniformity of nature ever been broken? The answer is, Not to the knowledge of science.*

"What has thus been stated in regard to *heat and gravity applies to the whole of inorganic nature.*"

It thus seems that the conservation of energy is a broad and general principle of almost universal application, and a pervading ray of truth that runs through all its manifestations points unmistakably to a corollary to the one great law.

(To be continued.)

MEDICATED SOAPS.

THE following is an abstract of an interesting paper on "Soaps, especially Medicated, in Diseases of the Skin," by Dr. John V. Shoemaker, of Philadelphia. The writer first discussed at some length the use of soap in health and disease, after which medicated soaps in disease were carefully considered. It was pointed out that both potash and soda soaps could be combined with various chemical substances to form medicated soaps of either the soft or the hard variety. Soap so prepared was shown to be an easy and convenient vehicle for cutaneous applications.

The value of potash soap medicated with tar, naphthol, carbolic acid, salicylic acid, sulphur, balsam of Peru, mercury, and other substances was next cited. The writer finally added that soda soap, medicated, had even a more extensive use in the treatment of diseases of the skin than potash soap into which certain drugs had been introduced. Soda soap could be medicated with a variety of substances that could also be conveniently and easily brought in contact with the diseased surface. It was not only a useful and cleanly vehicle for applying medicine, but it also rid the skin of all abnormal products, and removed the epidermis in a mild way, exposing the sensitive skin. Soda soap, like potash soap, should always be employed on a diseased surface with precaution, especially in beginning its use, whether it was the ordinary or the medicated variety.

Its effect should always be tried on a small spot, and, if acceptable, it could be used over the entire diseased surface. In some diseases a marked and beneficial effect would follow its application, and, by its repeated employment, it would readily be apparent how frequently it should be used. Sometimes medicated soap was well borne every day, or once or twice a week. Occasionally its use once in two or three weeks was sufficient, or only as occasion might require for carrying off the epidermis, for stimulating the skin, or for the removal of irritating secretions, crusts, scales, or extraneous matter. Again, it might happen in some cutaneous diseases that medicated or any form of soap was not well borne, or absolutely contraindicated by the abnormal condition of the skin. Attention to the precautions already alluded to, together with a general clinical knowledge of what was suitable or unsuitable to use, from the change in the skin, should serve as a sufficient guide as to whether medicated soap should or should not be employed.

A variety of medicinal substances and combinations had been tested by him in soda soap for some years, both in private practice and in dispensary and hospital service, with the effect of producing the following medicated soaps, which have been found advantageous, were manufactured by W. T. Baker & Co., of Philadelphia, and were now largely used in the Philadelphia Hospital for Skin Diseases. Each soap referred to was divided into pieces or cakes that had an average weight of three ounces and a half, or 1,680 grains.

Alum Soap.—Sapo aluminis, 10 per cent., was most useful in hyperidrosis and seborrhœa oleosa. It checked or assisted in relieving the discharge, and often brought the diseased surface into a condition suitable for other remedies. Many cases of pustular eczema, particularly in the subacute stage, were benefited by it. It freed the surface of crusts and scales, and aided in lessening the formation of pus. It was very efficient in all indolent conditions of the integument, as in lupus, cancer, and scrofulous and syphilitic skin affections. It had both a stimulating and an astringent action on ulcers, and would be found particularly good for bedsores and all weakened conditions of the skin from illness, or any irritation from friction, especially in the folds of the skin of stout persons, by giving strength and vigor to the skin.

Arnica Soap.—Sapo arnicæ, 10 per cent., was very good to use in sore nipples, and in many inflammatory affections around the mucous outlets of the body. It was likewise serviceable in cleansing boils, carbuncles, and many of the pustular skin affections. The irritable and sensitive condition of the skin that might exist during the course of these diseases was frequently relieved by its use. It was also an excellent application for abrasions, wounds, and bruises of the integument; soreness or pain, if present, was usually lessened or removed.

Boro-Glyceride Soap.—Sapo boro-glyceriti, 10 per cent., was preferable to either borax or boric-acid soap. It possessed antiseptic and deodorant properties, and was particularly applicable for the destruction of minute organisms. It was valuable for cleansing wounds, ulcers, suppurating, sloughing, or gangrenous surfaces, lessening inflammation, and preventing the action of atmospheric germs. General and local pruritic conditions of the skin, especially pruritus of the genital organs and the anus, were usually benefited and often relieved by its use. It was valuable in acne and in seborrhœa, freeing the surface in the latter disease of crusts or scales, opening the orifices of the sebaceous follicles, and lessening the accumulation of the abundant secretion. The roughened, reddened, and irritable state of the skin that was at times present in the latter disease and in acne rosacea was often removed by the use of this soap, and it might give a clear and healthy complexion.

Camphor Soap.—Sapo camphoræ, 10 per cent., had primarily a stimulant, and at times an irritant action, which was succeeded by an anodyne effect. It was most frequently used for the relief of the pruritus of eczema, chilblains, and other irritable affections of the skin.

Carbolic Acid Soap.—Sapo acidi carbolici, 5 per cent. had at first a stimulant action, followed usually by an anæsthetic effect. It had been largely employed for its antiseptic action in wounds and all suppurating sores, and the accompanying itching was often allayed by it. It was excellent for chronic eczema, psoriasis, and many other cutaneous diseases, but, on account of its unpleasant and penetrating odor, many persons preferred naphthol and salicylic-acid soaps.

Chamomile Soap.—Sapo anthemidis, 10 per cent., was a mild stimulant and astringent, possessing an agreeable aromatic odor, and being very acceptable in many inflammatory affections. It was excellent in intertrigo or chafing, and in dermatitis, seborrhœa, hyperidrosis, and bromidrosis, while it was particularly valuable, both for its medicinal virtues and its aromatic odor, in all conditions of excessive secretion and ill-smelling sores. It was frequently rendered more effective by the addition of sulphur, according to the following combination:

Chamomile and Sulphur Soap.—Sapo anthemidis sulphurisque, 10 per cent., possessed the properties of both remedies in the combination. In seborrhœa sicca on any part of the body, but more particularly on the scalp or portions covered with hair, it had a most decided effect in carrying off the scales and crusts from the surface. Loss of hair, so frequent from dandruff or seborrhœa sicca, could be relieved or checked by the use of this soap. The greasy, shining complexion, attended with numerous small elevations or pimples, a form of acne, common to young women from either gastric or menstrual disorders, often yielded to applications of it, and it assisted in restoring the skin to its healthy transparent state.

Eucalyptol Soap.—Sapo eucalyptoli, 5 per cent., had not only stimulating and astringent, but also pleasant balsamic qualities. It was, therefore, a useful disinfectant application to all foul-smelling wounds and ulcers. In fœtid perspiration it was very efficacious.

Naphthol Soap.—Sapo naphtholi, 5 per cent., was one of the most effective of all the medicated soaps. It was useful in very many cutaneous diseases, especially on account of being free from odor and having stimulating, astringent, and some anæsthetic effect upon the skin. Animal parasites on the skin or in the clothes were usually destroyed by its application. Lousiness, particularly of the pubic or axillary regions, could be easily, cleanly, and quickly destroyed by naphthol soap, superseding the filthy mercurial ointment. Scabies or itch was sometimes also eradicated by it, and it was a valuable adjuvant to other remedies. The bites or stings of many insects and animals could often be cured or relieved by its use. It often acted well in eczema, especially the subacute and chronic variety, adding much to lessen the infiltration and itching. Psoriasis, pityriasis, and ichthyosis were often benefited by it. It had decided antiseptic properties, and was, therefore, of great utility in all offensive discharges from the skin. Fœtid perspiration was not only controlled, but often cured by its use.

Salicylic Acid Soap.—Sapo acidi salicylici, 4 per cent., was excellent for its antiseptic action, and was by far superior to carbolic acid soap. Its freedom from the irritating quality and disagreeable odor of the latter soap made it preferable to it in every way. It was admirable for toilet purposes, and had proved serviceable in thickened conditions of the epidermis of the plantar, palmar, and extensor surfaces. It assisted in softening the epidermis, and in making the skin more natural and pliable. Sycosis and pustular eczema were generally benefited by its use, particularly when the hair became matted together and was accompanied with a fœtid odor. It was likewise serviceable in fœtid perspiration and all foul-smelling wounds or sores.

Sublimate Soap.—Sapo hydrargyri chloridi corrosivi, 1 per cent., was no doubt better known by the former term, as the latter had a bad signification in the minds of many for whom it might be necessary to prescribe it. It was, like carbolic acid, naphthol, and salicylic

AMBULANCE STRETCHER.

acid soaps, a valuable antiseptic. In truth, it might be preferred by many who now regarded the corrosive chloride of mercury as a better antiseptic than those already named, and it could be advantageously employed in the same class of affections. Sublimate soap might, however, be objected to for fear of producing salivation; but the risk with so small a quantity of mercury in the soap was extremely slight, and up to the present time he had never seen this effect. It was valuable in animal parasitic diseases, such as phtheiriasis, or lousiness, scabies, or itch, and for destroying insects of all varieties that might infest the body. Freckles, pigmentary deposits, especially chloasma, and yellowish, brown or blackish patches on the skin, were greatly relieved and sometimes removed by its employment. The red and roughened state of the skin that might follow the eruptive fevers, such as small-pox, might be improved by its use. It assisted in overcoming an unhealthy state of the skin, and in producing a clear and brilliant complexion. Sublimate soap was also one of the best agents in all kinds of itching, and might afford the greatest relief sometimes in both pruritus ani and pruritus pudendi. It was, likewise, markedly serviceable in the various syphilitic skin eruptions.

Tar Soap.—Sapo picis liquidæ, 10 per cent., had long been employed with great advantage in many forms of cutaneous disease. Eczema and psoriasis, more especially the chronic varieties, were frequently much improved by the use of tar soap. It assisted in keeping the skin active, and often lessened the infiltration and relieved the itching. It was useful also to remove the scales in pityriasis and ichthyosis. Tar soap or any of its compounds could be employed in many diseases of the skin that had been referred to in considering naphthol soap—the former being inferior to the latter on account of its disagreeable odor and the irritant effects that sometimes followed the application of tar to the skin.

The principal medicinal combinations with potash and soda soap have now been fully considered, and it simply remained to briefly refer to the following additional medicated ammonia and soda soaps, which had rather a limited use:

Amber Soap.—Eau de luce. A liquid soap which had as its chief ingredients tincture of oil of amber and balsam of Gilead, with water of ammonia. Used in enlarged glands, moles, warts, etc.

Balsam Soap.—5 per cent. Used in indolent ulcers, sinuses, abscesses, etc.

Elder Flower Soap.—Sapo sambuci florum, 10 per cent. Used in intertrigo, rosacea, sunburn, etc.

Ergot Soap.—Sapo ergotæ, 10 per cent. Used in eczema, acne rosacea, etc.

Glycerin Soap.—Sapo glycerini, 15 per cent. Used for roughness of the skin, chaps, pityriasis, etc.

Naphthol-Sulphur Soap.—Sapo naphtholi sulphurisque, 3 per cent. of naphthol and 10 per cent. of sulphur. Used in scabies (itch), phtheiriasis (lousiness), the presence of insects of all kinds on the skin, eczema, psoriasis, seborrhœa, hyperidrosis, bromidrosis, etc.

Sulphur Soap.—Sapo sulphuris, 10 per cent. Used in acne rosacea, etc.

Iodine Soap.—Sapo iodi, 3 per cent. Used in syphilitic and scrofulous skin affections, old granulations, etc.

Iodide of Sulphur Soap.—Sapo sulphuris iodidi, 3 per cent. Used in acne indurata, chronic ulcers, freckles, yellowish-brown of blackish patches or the skin, etc.

Kino Soap.—Sapo kino, 10 per cent. Used in eczema, rosacea, ulcers, etc.

Lead Soap.—Sapo plumbi, 3 per cent. Used in boils, carbuncles, abrasions, bed-sores, etc.

Tannin Soap.—Sapo acidi tannici, 3 per cent. Used in seborrhœa oleosa, excessive sweating, ulcers, granulations, etc.

Tannin Balsam Soap.—Sapo tanno-balsamicus, 2 per cent. of tannin and 5 per cent. of Peruvian balsam. Used in wounds, ulcers, chilblains, etc.

Thymol Soap.—Sapo thymoli, 3 per cent. Used in ulcers, wounds, abscesses, sinuses, pustular eczema, etc.

Turpentine Soap.—Sapo terebinthinæ compositus. This soap, known as Starkey's, was composed of equal parts of potassium carbonate, oil of turpentine, and Venice turpentine. Used in chilblains, syphilis, psoriasis, etc.

Wintergreen Soap.—Sapo gaultheriæ, 3 per cent. Used in eczema, psoriasis, lichen, acne, etc.

Witch Hazel Soap.—Sapo hamamelidis, 10 per cent. Used in fœtid perspiration, eczema, loss of hair, etc.

Soap, especially the medicated, as had been shown, was very often valuable in the treatment of the various diseases of the skin, provided it was properly and judiciously used. It was powerful to do good, and equally so to effect harmful results. The greatest care and the utmost precautions, as had already been pointed out, should always be exercised in applying it to a diseased surface, and too much must not be expected for soap to accomplish. The manufacturer, the merchant, and too often the physician, maintained that this or that medicated soap would remove or cure certain skin diseases, whereas on trial they would frequently be found to utterly fail. Soap, therefore, as a remedy *per se*, seldom cured cutaneous affections, but as an adjuvant it was one of the most valuable agents that we possessed.

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MR. TOZER, Chief Superintendent of the Birmingham Fire Brigade, has devised a new form of ambulance stretcher for the removal of injured persons, which promises to be very useful, and at the same time convenient. The apparatus is exceedingly simple—so much so as scarcely to need explanation, since the larger scaled section shows the method of opening and closing. The apparatus is inexpensive, and would be found serviceable in hospitals, police and fire brigade stations.

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